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ROCK ISLAND ARSENAL  
RESEARCH & DEVELOPMENT DIVISION  
DESIGN ENGINEERING BRANCH



TECHNICAL REPORT

CONTRIBUTION TO THE ANALYSIS OF  
MUZZLE BRAKE DESIGN

O. M. S. CODE NO.	5520.11.440A0.01
D. A. PROJECT NO.	5W01-01-034
REPORT NO.	62-1794
AUTHOR	George Schlenker
DATE	May 1962

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Report No. 62-1794

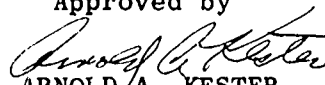
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CONTRIBUTION TO THE ANALYSIS OF  
MUZZLE BRAKE DESIGN

By

  
George Schlenker

Approved by

  
ARNOLD A. KESTER  
Chief, Design Engineering Branch

May 1962

OMS Code No. 5520.11.440A0.01

Department of the Army Project  
No 5W01-01-034

Rock Island Arsenal  
Rock Island, Illinois

## ABSTRACT

A theory of gaseous discharge from the end of a tube was constructed using an isentropic model with account taken of axial gradients in the state variables. On the assumption that the flow rates from such a tube were not appreciably altered by the presence of conventionally designed muzzle brakes, formulas for the forces on the brake and tube were obtained for brakes of various design.

In order to implement the computation of parameters associated with a complete brake analysis, a digital computer program was written for the Royal McBee, LGP-30 which permits one to perform an analysis with relative ease. This program is included in the report.

A comprehensive bibliography on muzzle brake studies, gun induced shock, and allied fields is also included in this report.

## TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT . . . . .	ii
TABLE OF CONTENTS . . . . .	iii
LIST OF SYMBOLS . . . . .	1
PART I . . . . .	1
PART II . . . . .	4
PART III . . . . .	7
SUBSCRIPTS . . . . .	9
SUPERSCRIPTS . . . . .	10
INTRODUCTION . . . . .	11
Figures 0.1 -- 0.4 . . . . .	13
EQUATIONS . . . . .	17
TABLES 0.1 -- 0.7 . . . . .	23
GRAPHS 0.1 -- 0.12 . . . . .	30
USE OF DIPARDIP . . . . .	42
LOGIC DIAGRAM . . . . .	47
STORAGE ALLOCATIONS . . . . .	55
CODING SHEETS . . . . .	68
SAMPLE BRAKE ANALYSES . . . . .	94
A Single-Baffle, Closed, Asymmetric Brake . .	96
A Triple-Baffle, Closed, Symmetric Brake . .	98
A Single-Baffle, Open Brake . . . . .	100
A Double-Baffle, Closed Brake with Free Periphery . . . . .	103

	<u>Page</u>
APPENDIX I. . . . .	104
Derivation of the formulas concerning momentum and energy distribution at start of discharge period.	
APPENDIX II. . . . .	109
Derivation of the relationships: $\phi_{AV}(\beta)$ , $\kappa_{AV}(\beta)$ , $\nu_{AV}(\beta)$	
APPENDIX III. . . . .	113
Derivation of the equations concerning state variables during the discharge period.	
APPENDIX IV. . . . .	124
Derivation of the equations relative to analysis of "closed brake" designs.	
APPENDIX V. . . . .	131
Derivation of the equations relative to analysis of "open brake" designs.	
APPENDIX VI. . . . .	137
Derivation of the equation for the vertical force in "free periphery" designs.	
BIBLIOGRAPHY . . . . .	139
ACKNOWLEDGEMENT . . . . .	142
DISTRIBUTION . . . . .	143

## LIST OF SYMBOLS

Due to the large number of parameters considered, the symbols used are divided into three classes: those applicable in general and in particular to the period prior to gas ejection, those concerned primarily with the period during which gas is discharged from the muzzle (discharge period), and lastly those concerned with the design of the brake. Any symbol not listed here or one having two meanings is defined in one of the appendices, where it first appears.

### PART I

#### GENERAL

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$\xi$	travel of projectile from beginning of rifling	inches
$g_0$	length of bore from beginning of rifling	inches
D	diameter of bore	inches
$r_N$	radius of a tube of cross sectional area A; also the radius of a sonic nozzle	inches
A	area of bore plus cross sectional area of grooves	$\text{in}^2$
$A_{\text{cnct}}$	area of ammunition band in contact with tube after shear deformation	$\text{in}^2$
$\mathcal{V}$	total internal volume	$\text{in}^3$
$\mathcal{V}_c$	volume of chamber	$\text{in}^3$
$M_p$	mass of projectile	$\text{lb}_m$
$M_c$	mass of charge	$\text{lb}_m$
$M_{\text{ig}}$	mass of igniter	$\text{lb}_m$
$M_T = M_c + M_{\text{ig}}$	total propellant mass	$\text{lb}_m$
$M_r$	mass of recoiling parts	$\text{lb}_m$



<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
T	temperature of the propellant gases	$^{\circ}\text{R}$
v	velocity (with subscripts)	ft/sec
$v_c$	muzzle velocity of the projectile	ft/sec
V	specific volume of the propellant gases	$\frac{\text{ft}^3}{\text{lb}_m}$
$\rho = \frac{1}{V}$	density	$\frac{\text{lb}_m}{\text{ft}^3}$
$p = p(t)$	pressure in the gas	psia
$P_{\text{max}}$	maximum pressure	psia
t	time	secs
$t_c$	time at which base of projectile leaves gun tube	secs
B(t)	force on breech	$\text{lb}_f$
a	speed of sound in gas	ft/sec
$M = \frac{v}{a}$	mach number in gas	
$\gamma = C_p/C_v$	ratio of specific heats of propellant gas	
$\mathcal{R}$	universal gas constant = 1545	$\frac{\text{lb}_f \text{ ft}}{\text{mole } ^{\circ}\text{R}}$
m	molecular weight of gas	$\frac{\text{lb}_m}{\text{mole}}$
$R = \frac{\mathcal{R}}{m}$	gas constant	$\frac{\text{lb}_f \text{ ft}}{\text{lb}_m ^{\circ}\text{R}}$
$C_p$	specific heat of gas at constant pressure	$\frac{\text{Btu}}{\text{lb}_m ^{\circ}\text{R}}$
$C_v$	specific heat of gas at constant volume	$\frac{\text{Btu}}{\text{lb}_m ^{\circ}\text{R}}$
J	Joule's constant = 777.5	$\frac{\text{lb}_f \text{ ft}}{\text{Btu}}$

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$g$	acceleration due to gravity = 32.17	ft/sec <sup>2</sup>
$e_c$	heat of explosion of the propellant charge	$\frac{\text{Btu}}{\text{lb}_m}$
$e_{ig}$	heat of explosion of the igniter	$\frac{\text{Btu}}{\text{lb}_m}$
$E$	energy involved in a process	Btu
KEP	kinetic energy of the projectile at $t = t_0$	Btu
KEG	kinetic energy of the gas at $t_0$	Btu
KER	kinetic energy of the recoiling parts at $t_0$	Btu
KEB	kinetic energy spent in engraving the bore and in forcing the projectile thru at $t_0$	Btu
$E_g$	energy remaining in the gas at $t_0$	Btu
$\mathcal{H}$	total heat released by charge and igniter during combustion	Btu
$\mathcal{H}_c$	heat released by charge	Btu
$\mathcal{H}_{ig}$	heat released by igniter	Btu
$x = \frac{1}{2} + \frac{v_c}{A}$	length of tube of uniform cross section	inches
$L = \frac{1}{2} + \frac{v_c}{A}$	length of tube of uniform cross section having an internal volume equal to $v_r$	inches
$\eta = \frac{x}{L}$	dimensionless length	
$a = \frac{v_e}{a_b}$	dimensionless velocity	
$\beta = \frac{v_0}{a_{av \text{ init}}}$	dimensionless velocity	
$\phi = \frac{p}{p_b} = \phi(\eta)$	dimensionless pressure at $t_0$	
$\zeta = \frac{v}{v_b} = \zeta(\eta)$	dimensionless specific volume at $t_0$	
$\mathcal{T} = \frac{T}{T_b} = \mathcal{T}(\eta)$	dimensionless temperature at $t_0$ ; also used as an angle in the brake design	degrees

PART II

LIST OF SYMBOLS  
PERTAINING TO THE DISCHARGE PERIOD

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$z$	axial distance measured positively in streamwise direction	inches
$r$	radial distance from axis	inches
$P_b = p$	pressure at the breech (written in digital computer program without the subscript)	psia
$P_c$	pressure at the muzzle	psia
$B$	breech force	$lb_f$
$P$	cumulative momentum discharged	$lb_f \text{ secs}$
$M$	cumulative mass discharged	$lb_m$
$B_T = B_{cml}$	breech impulse	$lb_f \text{ secs}$
$H$	cumulative stagnation enthalpy discharged from the muzzle	Btu
$F_z$	force on brake in axial direction of gun tube	$lb_f$
$F_y$	force on brake normal to axis of gun tube	$lb_f$
$I_z$	resultant impulse received by brake and gun tube during gas discharge in axial direction	$lb_f \text{ secs}$
$I_y$	impulse received by brake and gun tube in the normal direction	$lb_f \text{ secs}$
$\alpha_T =$	$\frac{A \ g \ P_b \ \text{init}}{a_b \ \text{init} \ M_T}$ ; dimensional constant used in formulas in Appendix III	$\text{secs}^{-1}$
$\tau = \alpha_T t$	dimensionless time	
$\Phi =$	$\frac{P_b}{P_b \ \text{init}}$ ; dimensionless breech pressure, defined in Appendix III	

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$\Phi_T =$	$\frac{B_T \alpha_T}{A p_{b \text{ init}}}$ ; dimensionless cumulative breach impulse, defined in Appendix III	
$\mu =$	$\frac{\dot{P}}{A p_{b \text{ init}}}$ ; dimensionless momentum rate of discharge, defined in Appendix III	
$\mu_T =$	$\frac{P g}{M_T a_{b \text{ init}}}$ ; dimensionless cumulative momentum discharged from muzzle, defined in Appendix III	
$\nu =$	$\frac{\dot{M}}{M_T \alpha_T} = \left[ \frac{g A p_{b \text{ init}}}{a_{b \text{ init}}} \right]^{-1} \dot{M}$ ; dimensionless mass rate of discharge, defined in Appendix III	
$\nu_T =$	$\frac{M}{M_T}$ ; dimensionless cumulative mass discharged, defined in Appendix III	
$\eta =$	$\frac{\dot{H}}{E_g \alpha_T}$ ; dimensionless stagnation enthalpy rate of discharge, defined in Appendix III	
$\eta_T =$	$\frac{H}{E_g}$ ; dimensionless cumulative stagnation enthalpy discharged, defined in Appendix III	
$\epsilon$	expansion ratio, i.e., ratio of cross sectional area of gas flow at any axial station to area of muzzle	
$n$	speed-up factor, i.e., ratio of one- dimensional velocity of gas at any station to velocity of gas at the muzzle	dimensionless
$\Delta$	empirical divergence angle of the flow with respect to the axis at entrance to a control volume surround- ing the baffle (Appendix V)	radians

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$\sigma = \frac{z}{r_N}$	dimensionless axial or stream-wise distance	
$\lambda = \frac{r}{r_N} = \frac{y}{r_N}$	dimensionless radial or lateral distance	
$\left. \begin{matrix} a \\ b_1 \\ b_2 \\ b_3 \end{matrix} \right\}$	coefficients used in a cubic fit of the shock boundary of the jet for $\sigma_m < 2$ ; $y_m = \lambda_m = \lambda_m(\sigma_m)$ $\lambda_m = a + b_1 \sigma_m + b_2 \sigma_m^2 + b_3 \sigma_m^3$	
$\left. \begin{matrix} a \\ b_1' \\ b_2' \end{matrix} \right\}$	coefficients used in a quadratic fit of the shock boundary of the jet for $\sigma_m \geq 2$ ; $\lambda_m = a' + b_1' \sigma_m + b_2' \sigma_m^2$	
$\alpha_j, \beta_{ij}$	coefficients used in a cubic fit of shock boundary coefficients: $a = a(p_o/p_\infty)$ , $b_1 = b_1(p_o/p_\infty)$ , etc.	
$\alpha_j', \beta_{ij}'$	coefficients used in a cubic fit of shock boundary coefficients: $a = a'(p_o/p_\infty)$ , $b_1' = b_1'(p_o/p_\infty)$ , and $b_2' = b_2'(p_o/p_\infty)$	

## PART III

LIST OF SYMBOLS  
PERTAINING TO BRAKE DESIGN

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$z$	axial direction of brake measured positively away from breech	inches
$y$	direction normal to axis of brake measured positively upwards when gun tube is horizontal	inches
$\alpha_j$	angle thru which gas is deflected with respect to the $z$ - direction	radians
$\beta_j$	angle thru which gas is deflected with respect to the $y$ - direction in a plane normal to the $z$ - axis. See figure 4.2 in appendix IV.	radians
$S_{ij}$ , $i=0,1,2$	closed-baffle port areas, used with subscripts to indicate the baffle referred to in a multi-baffle brake. See figure 4.1 in appendix IV.	
$r_j$	ratio of the mass flow rate captured by the $j$ th baffle to the mass flow rate of gas from the muzzle	
$K_j$	ratio of the mass flow rate of gas passing the $j$ th baffle undeflected to the mass flow rate from the muzzle	
$\lambda = \frac{F_z}{\dot{p}}$	ratio of axial brake force to momentum rate of discharge, $\dot{p}$	
$\lambda_r$	ratio of resultant momentum rate of discharge in the $z$ -direction thru a control volume enclosing only the brake orifices to the momentum rate of discharge from the muzzle	
$\omega = \frac{F_y}{\dot{p}}$	ratio of normal brake force to momentum rate of discharge	

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$b = \frac{F_z}{B}$	momentum index, i.e., the ratio of the axial brake force to the breech force	
$\left. \begin{matrix} f_0 \\ f_1 \\ f_2 \\ f_3 \end{matrix} \right\}$	empirical correction factors	
$\psi_{ij}, i = 1, 2, 3$	angles associated with free-periphery brake design. See appendix VI.	radians
$z_m$	distance from muzzle to projection of rim of open baffle on z- axis. See figure 5.1b in appendix V.	inches
$y_m$	radial distance at $z_m$ from axis to shock envelope	inches
$I$	inner radius in open brake design. See figure 5.1b in appendix V.	inches
$Q$	outer radius in open brake design. See figure 5.1b in appendix V.	inches

## SUBSCRIPTS

°	refers to conditions at projectile ejection
$\infty$	refers to ambient conditions
g	pertains to the gas
p	pertains to the projectile
r	pertains to the recoiling parts
ig	pertains to the igniter
c	pertains to the charge
b	refers to value of variable at the breech
eff	refers to an effective value
av	refers to an average value
max	refers to a maximum value
init	refers to initial conditions for gas ejection
T	refers to a cumulative or integrated value
i	dummy index; takes integral values from 0 to m
j	dummy index representing the baffle number; take integral values from 1 to N
0,1,2,...	indicates coefficient in power series, baffle number, and, in general, distinguishes members of a set



### SUPERSCRIPTS

- °            refers to a stagnation value
- .            indicates first deviative of variable  
             with respect to time
- '            indicates value of variable at time gases  
             become sonic at the muzzle
- indicates a mean value

## INTRODUCTION

The primary purpose of this study was to establish a reliable and convenient means for analysing the internal ballistics of an artillery piece during the gas discharge period and for evaluating the performance of an associated muzzle brake of one of a number of different configurations. Several standard brake designs and some novel designs were considered and are examined separately later in this report.

A secondary motive for this study was to establish relations for computing parameters useful in other studies such as shock establishment and decay.

The method of approach to the determination of internal ballistic parameters during the gas discharge period involves several assumptions:

- 1) that, at the advent of discharge, all of the propellant is burnt;
- 2) that the heat released by the reaction may be computed by taking the sum of the product of the heat of explosion of the igniter and its mass and that of the propellant and its mass;
- 3) that the amount of gas discharged after projectile ejection necessary to make the gas velocity at the muzzle sonic is negligible;
- 4) that the gas discharge proceeds nearly isentropically;
- 5) and that the presence of the muzzle brake does not appreciably affect the discharge rate from the muzzle.

To obtain accurate initial conditions for the gas discharge period the following method was used. An analysis of energy disposition prior to gas discharge was made (Appendix I). As a result of this analysis one can compute the total thermal energy remaining in the gas at the advent of gas discharge. From the latter value, one can compute the average temperature and pressure at the start of discharge. By making certain assumptions regarding momentum transport within the tube prior to gas discharge, one can predict the relationship that exists between the average values of the temperature, pressure, and specific volume and the values of these parameters at the breech. This derivation is made in appendix II. These values, then, are used as initial conditions for the nearly isentropic flow from the muzzle

With the initial breech pressure and specific volume given, one assumes that the gas rapidly becomes sonic at the muzzle. By applying isentropic flow theory, one can obtain expressions for the breech pressure and breech force, the momentum rate of discharge, the mass rate of discharge, the stagnation enthalpy rate of discharge, and integrals of all of these. See Appendix III. It was found that convenient non-dimensional expressions for these parameters could be obtained in terms of a dimensionless time  $\tau$ . Evaluation of these expressions provided a set of tables suitable for use with dimensional constants in obtaining the dimensional parameters relative to the discharge period. A computer program which takes certain thermodynamic data and computes the dimensional parameters was given the acronym "DIPARDIP."

DIPARDIP also requires muzzle brake data and furnishes loads and impulses on the brake as well as the effective momentum index. Use of this program and some typical results are described in later sections of the report. A special feature of this program is the large number of different brake designs which can be analysed.

In order to clarify what is meant by the terms "closed brake" and "open brake" designs, the reader is referred to figures 0.1 thru 0.4. Appendix IV treats the analysis of the closed brake design. Appendix V treats open brake design, and the special equations for the free periphery design are derived in Appendix VI.

In the next section all of the equations used by DIPARDIP are presented together with tables, graphs of tables, and graphs of some of the equations. These graphs and tables could be used for a hand calculation of the equations in lieu of DIPARDIP. For the derivation of any of the equations, the reader is referred to the appendices.



Figure 0.1  
A SINGLE-BAFFLE,  
CLOSED ASYMMETRIC  
BRAKE

11-070-2150-L9

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3 January 1962

HOWITZER, LIGHT, TOWED, 105mm, XM102. UBU MUZZLE BRAKE.

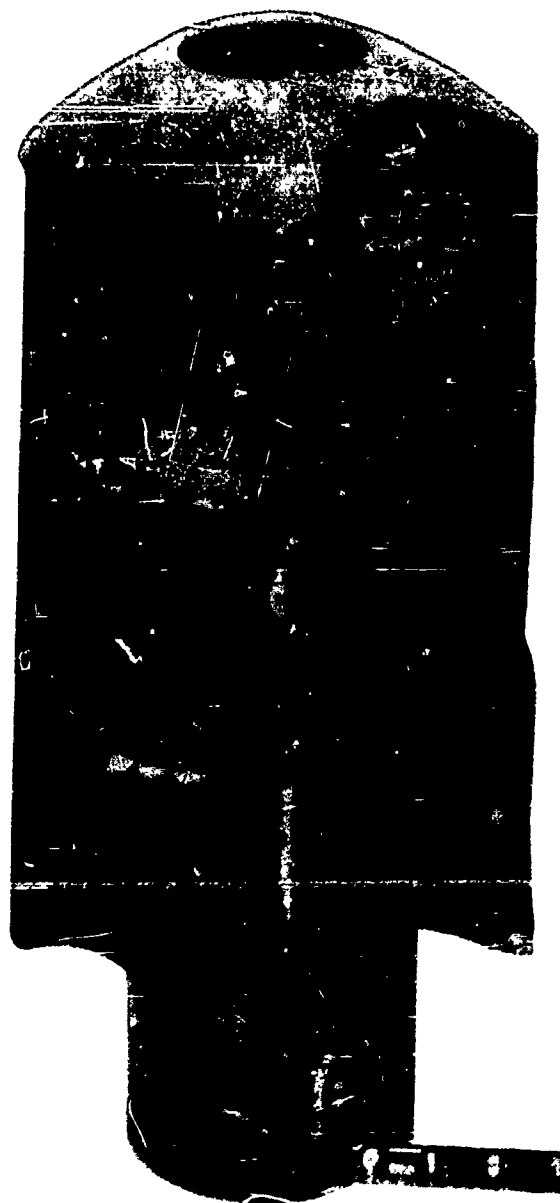


Figure 0.2

A TRIPLE-BAFFLE,  
CLOSED SYMMETRIC  
BRAKE



Figure 0.3  
A SINGLE-BAFFLE,  
OPEN BRAKE

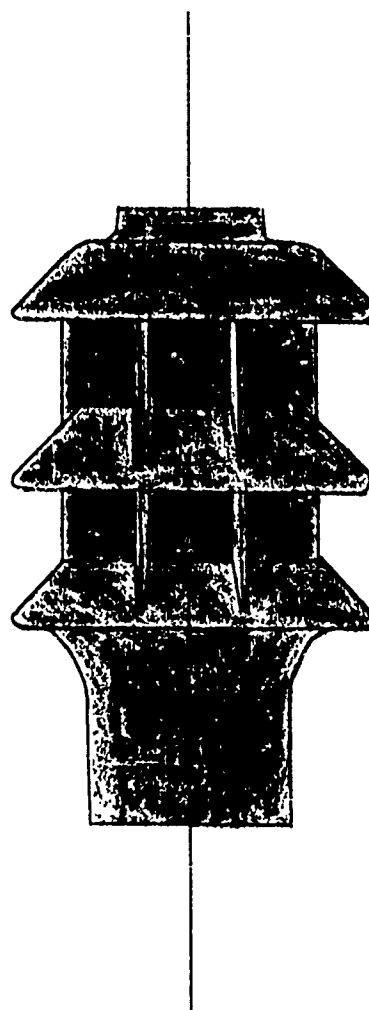
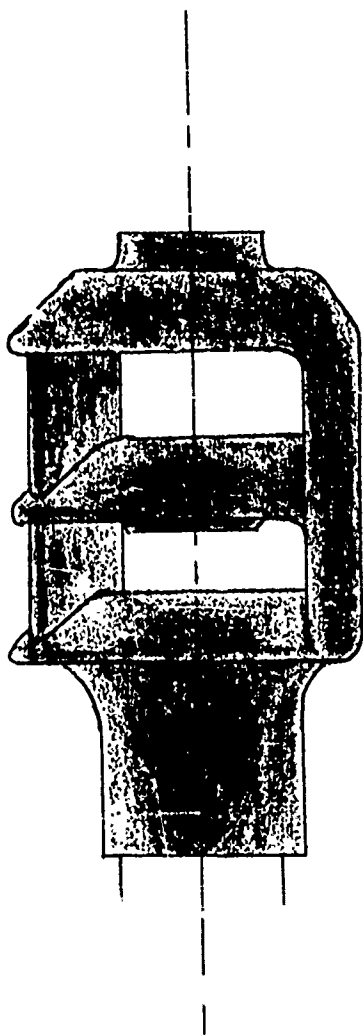


Figure 0.4  
A DOUBLE-BAFFLE,  
CLOSED BRAKE WITH  
FREE PERIPHERY

# EQUATIONS

$$0.1 \quad \mathcal{H}_{ig} = e_{ig} M_{ig}$$

$$0.2 \quad \mathcal{H}_c = e_c M_c$$

$$0.3 \quad \mathcal{H} = \mathcal{H}_{ig} + \mathcal{H}_c$$

$$0.4 \quad \text{KEP} = \frac{M_p v_o^2}{2 g J}$$

$$0.5 \quad \text{KEG} = \frac{M_T v_o^2}{2 g J} (\text{const})$$

$$0.6 \quad \text{const.} =$$

$$1/3 \left( \frac{1+v_r}{v_o} \right)^2 + \left( \frac{v_r}{v_o} \right)^2 - \frac{v_r}{v_o} \left( \frac{1+v_r}{v_o} \right), \text{ where}$$

$$\frac{v_r}{v_o} = \frac{\frac{M_T + M_p}{2}}{\frac{M_T + M_r}{2}}$$

$$0.7 \quad \text{KER} = \frac{M_r v_r^2}{2 g J}$$

$$0.8 \quad \text{KEB} = \frac{.18 A_{\text{cnct}}}{A} (\text{KEP})$$

$$0.9 \quad E_g = \mathcal{H} - \Sigma(\text{kinetic energies})$$

$$0.10 \quad T_{av \text{ init}} = T_g = \frac{E_g (\gamma - 1) J}{R M_T}$$

$$0.11 \quad p_{av \text{ init}} = p_g = \frac{12 E (\gamma - 1) J}{v_r}$$

$$0.12 \quad a_{av \text{ init}} = (\gamma g R T_{av \text{ init}})^{1/2}$$

$$0.13 \quad \beta = \frac{v_o}{a_{av \text{ init}}}$$

$$0.14 \quad \phi_{av} = 1.0495200 - .25021815\beta - .061082024\beta^2$$

$$0.15 \quad \chi_{av} = .97960297 + .10274869\beta + .19109947\beta^2$$



$$0.16 \quad \gamma_{av} = \phi_{av} \kappa_{av}$$

$$0.17 \quad p_{b \text{ init}} = \left( \frac{p_{2v}}{\phi_{av}} \right)_{\text{init}}$$

$$0.18 \quad v_{b \text{ init}} = \left( \frac{v_{av}}{\kappa_{av}} \right)_{\text{init}}$$

$$0.19 \quad a_{b \text{ init}} = \frac{a_{av \text{ init}}}{(\gamma_{av})^{1/2}}$$

$$0.20 \quad \alpha_{\tau} = \frac{A g p_{b \text{ init}}}{a_{b \text{ init}} M_{\tau}}$$

$$0.21 \quad t = \frac{\tau}{\alpha_{\tau}}$$

$$0.22 \quad p_b = p = p_{b \text{ init}} \Phi$$

$$0.23 \quad B = A p_{b \text{ init}} \Phi$$

$$0.24 \text{ a) } B_{\tau} = \frac{A p_{b \text{ init}}}{\alpha_{\tau}} \Phi_{\tau}$$

$$\text{b) } B_{\tau} = \frac{a_{b \text{ init}} M_{\tau}}{g} \Phi_{\tau}$$

$$0.25 \quad \dot{p} = A p_{b \text{ init}} \mu$$

$$0.26 \quad \dot{p} = \frac{a_{b \text{ init}} M_{\tau}}{g} \mu_{\tau}$$

$$0.27 \quad \dot{M} = \left( \frac{g A p_{b \text{ init}}}{a_{b \text{ init}}} \right) \nu$$

$$0.28 \quad M = M_{\tau} \nu_{\tau}$$

$$0.29 \quad \dot{H} = E_g \alpha_{\tau} \eta$$

$$0.30 \quad H = E_g \eta_{\tau}$$

EQUATIONS FOR SYMMETRICAL  
AND ASYMMETRICAL CLOSED BRAKES

$$0.31 \text{ a)} \quad \epsilon_{1j} = \left( \frac{S_{0j} + S_{1j}}{S_{0j-1}} \right) \epsilon_{1j-1} ,$$

where b)  $\epsilon_{10} = 1$

c)  $S_{00} = A$  and  $j$  is the number of the baffle

$$0.32 \quad \epsilon_{2j} = \frac{S_{2j}}{S_{1j}} \epsilon_{1j}$$

$$0.33 \quad n_{1j} = n(\epsilon_{1j}) \quad \left. \vphantom{\begin{matrix} n_{1j} \\ n_{2j} \end{matrix}} \right\} \text{Function is tabulated,}$$

$$0.34 \quad n_{2j} = n(\epsilon_{2j})$$

$$0.35 \quad v_{1j} = a_0 n_{1j}$$

$$0.36 \quad v_{2j} = a_0 n_{2j}$$

$$0.37 \quad \dot{M}_{2j} = r_j \dot{M}_0$$

$$0.38 \text{ a)} \quad r_j = \left( \frac{S_{1j}}{S_{0j} + S_{1j}} \right) K_{j-1} , \text{ where}$$

b)  $K_0 = 1$

$$0.39 \quad K_j = \left( \frac{S_{0j}}{S_{0j} + S_{1j}} \right) K_{j-1}$$

$$0.40 \quad \lambda_r = \frac{\sum_{j=1}^N [n_{2j} r_j \cos \alpha_j] + n_{1N} (1 - \sum_{j=1}^N r_j)}{f_2} \text{ or}$$

$$\lambda_r = (aps - n_{1N}(1-bps))/f_2$$

$$0.41 \text{ a)} \quad aps = \sum_{j=1}^N r_j n_{2j} \cos \alpha_j$$

b)  $bps = \sum_{j=1}^N r_j$

c)  $cps = \sum_{j=1}^N r_j n_{2j} \cos \beta_j$

d)  $dps = \sum_{j=1}^N r_j n_{1j}$

$$0.42 \quad \omega = \frac{\sum_{j=1}^N r_j n_{2j} \cos \beta_j}{f_1} \quad \text{or}$$

$$\omega = \frac{\text{cps}}{f_1}$$

$$0.43 \quad \lambda = \frac{\sum_{j=1}^N r_j (n_{1j} - n_{2j} \cos \alpha_j)}{f_0}$$

$$\text{or } \lambda = \frac{\text{aps} - \text{aps}}{f_0}$$

$$0.44 \quad b = \frac{\dot{p}}{B} \lambda$$

$$0.45 \quad F_z = \lambda \dot{p}$$

$$0.46 \quad F_z = b B$$

$$0.47 \quad F_y = \omega \dot{p}$$

$$0.48 \quad I_z = B_T - \lambda P \quad \text{or}$$

$$I_z = (1 - b) B_T$$

$$0.49 \quad I_y = \omega P$$

#### EQUATIONS FOR SINGLE-BAFFLE SYMMETRICAL OPEN BRAKES

$$0.50 \quad b = \frac{\dot{p}}{B} n_{21} r_1 \cos \Delta (1 - \cos \alpha_1),$$

$$\text{where } \cos \Delta \cong 1$$

$$0.51 \quad r_1 = 1 - \frac{I^2}{y_m^2}, \quad \text{for } y_m \leq Q$$

$$\text{or } r_1 = \left(1 - \frac{\nu^2}{\pi}\right) + \frac{\left(\frac{\nu^2}{\pi} Q^2 - I^2\right)}{y_m^2}, \quad \text{for } y_m > Q$$

$$0.52 \quad n_{21} = n(\epsilon_{21})$$

$$0.53 \quad \epsilon_{21} = 1 + \frac{\nu^2}{\pi} \lambda_m^2$$

$$0.54a \quad \lambda_m = y_m/r_N$$

$$0.54b \quad r_N = (A/\pi)^{1/2}$$

$$0.55 \quad \sigma_m = \frac{z_m}{r_N}$$

$$0.55 \ a) \quad \lambda_m = a + b_1 \sigma_m + b_2 \sigma_m^2 + b_3 \sigma_m^3, \text{ for } \sigma_m < 2$$

$$b) \quad \lambda_m = a' + b'_1 \sigma_m + b'_2 \sigma_m^2, \text{ for } \sigma_m > 2$$

$$0.57 \quad \frac{p_o}{p_\infty} = \frac{p_b}{(1+\gamma) p_\infty}$$

$$0.58 \quad a = \alpha_0 + \beta_{10} \left(\frac{p_o}{p_\infty}\right) + \beta_{20} \left(\frac{p_o}{p_\infty}\right)^2 + \beta_{30} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b_1 = \alpha_1 + \beta_{11} \left(\frac{p_o}{p_\infty}\right) + \beta_{21} \left(\frac{p_o}{p_\infty}\right)^2 + \beta_{31} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b_2 = \alpha_2 + \beta_{12} \left(\frac{p_o}{p_\infty}\right) + \beta_{22} \left(\frac{p_o}{p_\infty}\right)^2 + \beta_{32} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b_3 = \alpha_3 + \beta_{13} \left(\frac{p_o}{p_\infty}\right) + \beta_{23} \left(\frac{p_o}{p_\infty}\right)^2 + \beta_{33} \left(\frac{p_o}{p_\infty}\right)^3$$

$$0.59 \quad a' = \alpha'_0 + \beta'_{10} \left(\frac{p_o}{p_\infty}\right) + \beta'_{20} \left(\frac{p_o}{p_\infty}\right)^2 + \beta'_{30} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b'_1 = \alpha'_1 + \beta'_{11} \left(\frac{p_o}{p_\infty}\right) + \beta'_{21} \left(\frac{p_o}{p_\infty}\right)^2 + \beta'_{31} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b'_2 = \alpha'_2 + \beta'_{12} \left(\frac{p_o}{p_\infty}\right) + \beta'_{22} \left(\frac{p_o}{p_\infty}\right)^2 + \beta'_{32} \left(\frac{p_o}{p_\infty}\right)^3$$

$$0.60 \quad I_z = \sum_{i=1}^N (1-b_i) (B_{Ti} - B_{Ti-1}) \quad \text{or}$$

$$I_z = B_{TN} - \sum_{i=1}^N b_i (B_{Ti} - B_{Ti-1}),$$

$$\text{where } B_{T0} = 0$$

$$0.61 \quad b_{\text{eff}} = \frac{\sum_{i=1}^N b_i (B_{Ti} - B_{Ti-1})}{B_{TN}}$$

$$0.62 \quad I_z = B_{TN} (1 - b_{\text{eff}})$$

$$0.63 \quad \omega = 0, \text{ for a symmetrical brake}$$

$$0.64 \quad \lambda_r = n_{21} r_1 \cos \alpha_1 + n_{21} (1-r_1)$$

EQUATION FOR FREE-PERIPHERY BRAKE

$$0.65 \quad \omega = \frac{1}{\pi} \sum_j n_{2j} r_j [\cos \nu_{1j} - \cos \nu_{2j} + \sin \nu_{3j} (\pi/2 - \nu_{1j})]$$

$\tau$	$\Xi$	$\mu$	$\nu$
.10	.91138	.62049	.68128
.20	.83134	.56600	.62736
.30	.75899	.51674	.57815
.40	.69352	.47216	.53321
.50	.63422	.43179	.49213
.70	.53169	.36199	.42013
1.00	.41052	.27949	.33314
1.30	.31910	.21725	.26575
1.60	.24962	.16995	.21321
2.00	.18162	.12365	.16029
2.50	.12377	.084268	.11364
3.10	.079635	.054217	.076510
3.70	.052227	.035557	.052405
4.50	.030576	.020817	.032418
6.10	.011365	.0077378	.013343
7.50	.0051568	.0035109	.0065672

Table 0.1

$\tau$	$\bar{\Phi}_\tau$	$\mu_\tau$	$\nu_\tau$
.10	.095494	.065014	.071039
.20	.18256	.12429	.13643
.30	.26202	.17839	.19667
.40	.33459	.22780	.25220
.50	.40093	.27297	.30344
.70	.51719	.35211	.39445
1.00	.65755	.44775	.50688
1.30	.76646	.52183	.59629
1.60	.85130	.57958	.66781
2.00	.93675	.63776	.74195
2.50	1.01209	.68905	.80969
3.10	1.07204	.72987	.86592
3.75	1.11096	.75637	.90408
4.50	1.14323	.77834	.93730
6.10	1.17404	.79931	.97143
7.50	1.18498	.80676	.98474

Table 0.2

$\tau$	$\eta$	$\eta_{\tau}$
.10	.84170	.088621
.20	.76055	.16866
.30	.68788	.24101
.40	.62273	.30648
.50	.56427	.36578
.70	.46454	.46831
1.00	.34925	.58948
1.30	.26452	.68090
1.60	.20176	.75038
2.00	.14207	.81838
2.50	.093072	.87622
3.10	.057223	.92037
3.75	.035934	.94777
4.50	.019909	.96942
6.10	.0066835	.98863
7.50	.0027956	.99484

Table 0.3



$\beta$	$\Phi_{av}$	$\kappa_{av}$	$\mathcal{J}_{av}$
.4535	.92324	1.06639	.98453
.5047	.90800	1.08088	.98144
.5561	.89197	1.09665	.97818
.6077	.87532	1.11364	.97479
.6595	.85821	1.13177	.97129
.7116	.84079	1.15097	.96772
.7638	.82321	1.17117	.96411
.8163	.80557	1.19230	.96048

Table 0.4

TABLE 0.5

$\eta$	$\epsilon$
1.0000	1.00058
1.1000	1.00631
1.1750	1.02471
1.2500	1.05571
1.3000	1.08392
1.3500	1.11876
1.4000	1.16089
1.4500	1.21118
1.5000	1.27072
1.5500	1.34089
1.6000	1.42340
1.6500	1.52040
1.7000	1.63460
1.7500	1.76943
1.8000	1.92926
1.8500	2.11970
1.9000	2.34809
1.9750	2.78365
2.0500	3.37414
2.1250	4.19466
2.2000	5.36933
2.2750	7.11299
2.3500	9.81834
2.4250	14.25250
2.5000	22.04302
2.5750	37.02652
2.6250	69.60049
2.7250	153.98911
2.8000	441.19018

Coefficients for Cubic Fit of  $a_1$ ,  $b_1$ ,  $b_2$ , and  $b_3$

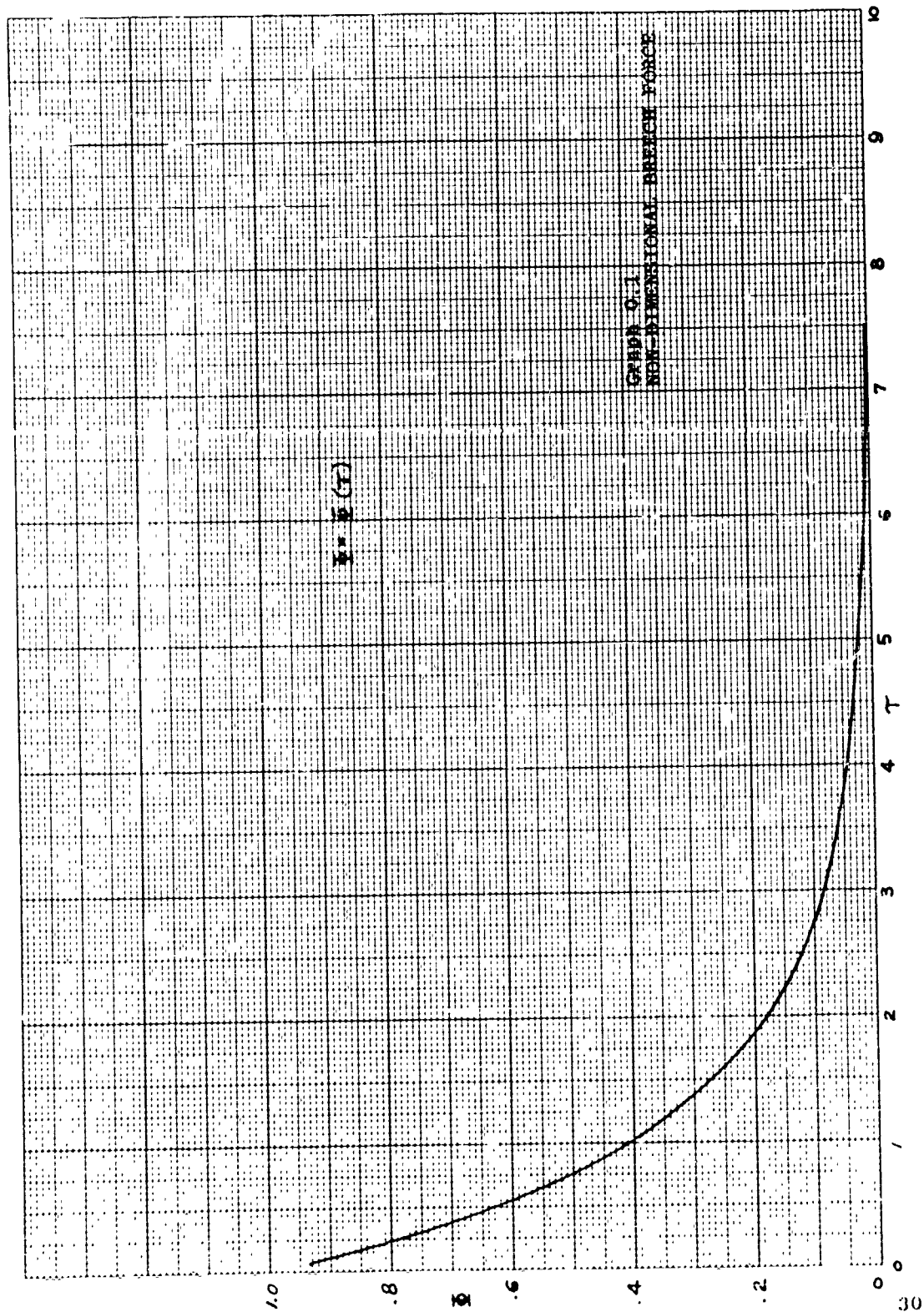
SET I				$j =$
$\alpha_j$	$\beta_{1,j}$	$\beta_{2,j}$	$\beta_{3,j}$	
1.0029575x10 <sup>0</sup>	9.7146227x10 <sup>-4</sup>	-1.2464600x10 <sup>-5</sup>	1.6405071x10 <sup>-7</sup>	0
1.3227139x10 <sup>-1</sup>	8.7822392x10 <sup>-2</sup>	-2.1672912x10 <sup>-3</sup>	2.2107067x10 <sup>-5</sup>	1
-8.2074898x10 <sup>-2</sup>	-2.0354335x10 <sup>-2</sup>	3.5434135x10 <sup>-4</sup>	-3.1316625x10 <sup>-6</sup>	2
1.3076924x10 <sup>-2</sup>	3.2693895x10 <sup>-3</sup>	-2.2656165x10 <sup>-5</sup>	1.6469917x10 <sup>-8</sup>	3
SET II				$j =$
$\alpha_j$	$\beta_{1,j}$	$\beta_{2,j}$	$\beta_{3,j}$	
1.0112126x10 <sup>0</sup>	5.1616179x10 <sup>-4</sup>	1.9529640x10 <sup>-6</sup>	-2.9900434x10 <sup>-9</sup>	0
9.3730118x10 <sup>-1</sup>	1.8788970x10 <sup>-2</sup>	-5.3483022x10 <sup>-5</sup>	7.4938991x10 <sup>-8</sup>	1
-2.5026538x10 <sup>-1</sup>	-7.5733961x10 <sup>-3</sup>	1.8646556x10 <sup>-5</sup>	-2.6977477x10 <sup>-8</sup>	2
4.3505442x10 <sup>-2</sup>	1.6938484x10 <sup>-3</sup>	-3.4027765x10 <sup>-6</sup>	4.3278227x10 <sup>-9</sup>	3

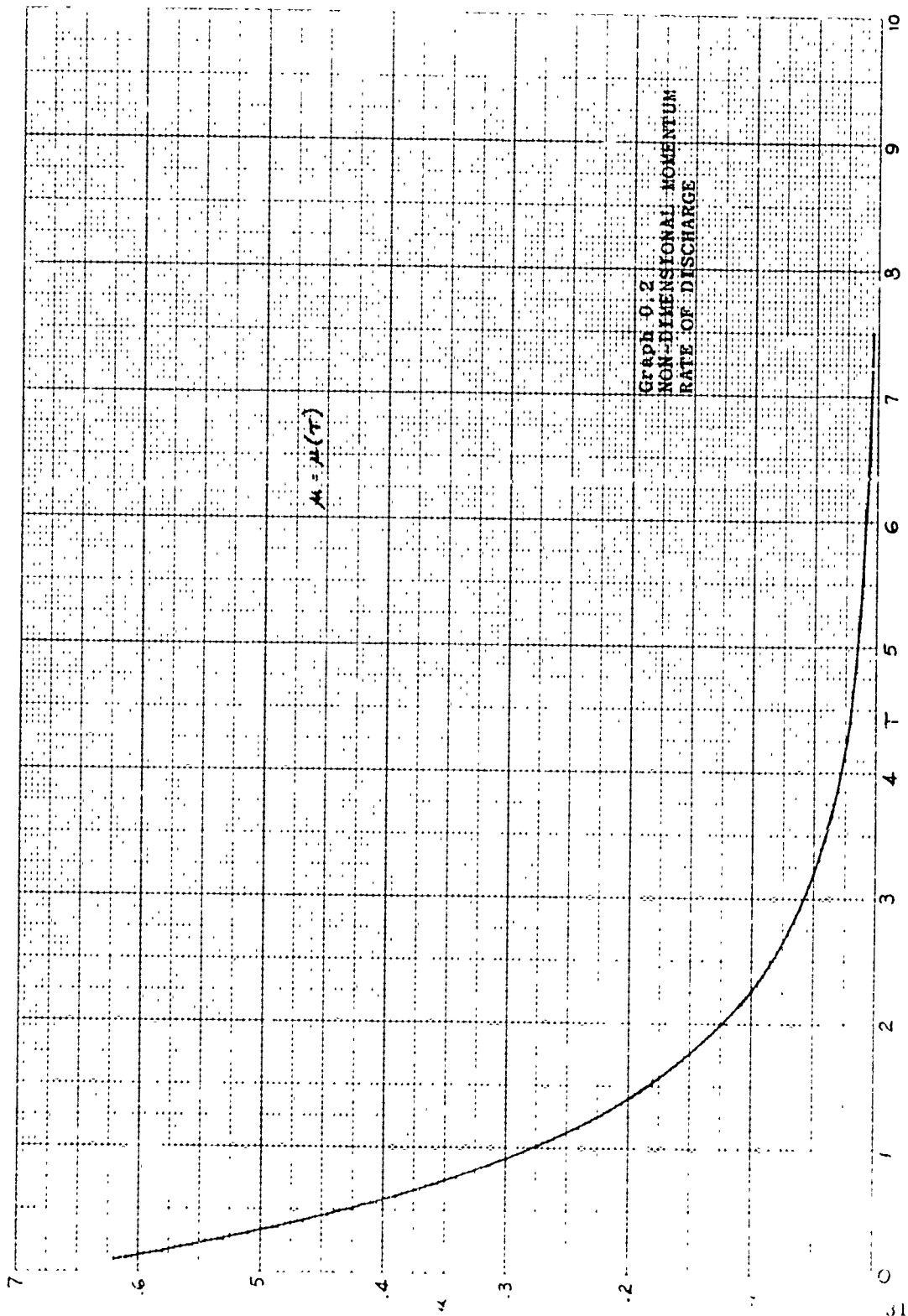
Table 0.6

Coefficients for Cubic Fit of  $a'_i$ ,  $b'_i$ , and  $b'_2$

$\alpha'_j$	SET I			$\beta'_{a_j}$	$j = 0$
	$\beta'_{i,j}$	$\beta'_{i,j}$	$\beta'_{i,j}$		
1.1788745x10 <sup>0</sup>	9.8121657x10 <sup>-3</sup>	-5.5985875x10 <sup>-5</sup>	1.5484761x10 <sup>-7</sup>	1	0
2.0359081x10 <sup>-1</sup>	2.0669444x10 <sup>-2</sup>	-1.4975523x10 <sup>-4</sup>	4.0250616x10 <sup>-7</sup>	1	1
-2.3007762x10 <sup>-2</sup>	-5.5381965x10 <sup>-4</sup>	4.2869848x10 <sup>-6</sup>	-1.2578841x10 <sup>-8</sup>	2	2
	SET II				
	$\beta'_{i,j}$	$\beta'_{i,j}$	$\beta'_{i,j}$		
	$\beta'_{i,j}$	$\beta'_{i,j}$	$\beta'_{i,j}$		
1.200684x10 <sup>0</sup>	4.825827x10 <sup>-3</sup>	3.690608x10 <sup>-6</sup>	-2.377028x10 <sup>-8</sup>	0	0
8.452055x10 <sup>-1</sup>	5.898632x10 <sup>-3</sup>	-2.323279x10 <sup>-5</sup>	4.253296x10 <sup>-8</sup>	1	1
-2.753219x10 <sup>-2</sup>	-6.423429x10 <sup>-4</sup>	4.200171x10 <sup>-6</sup>	-8.089821x10 <sup>-9</sup>	2	2

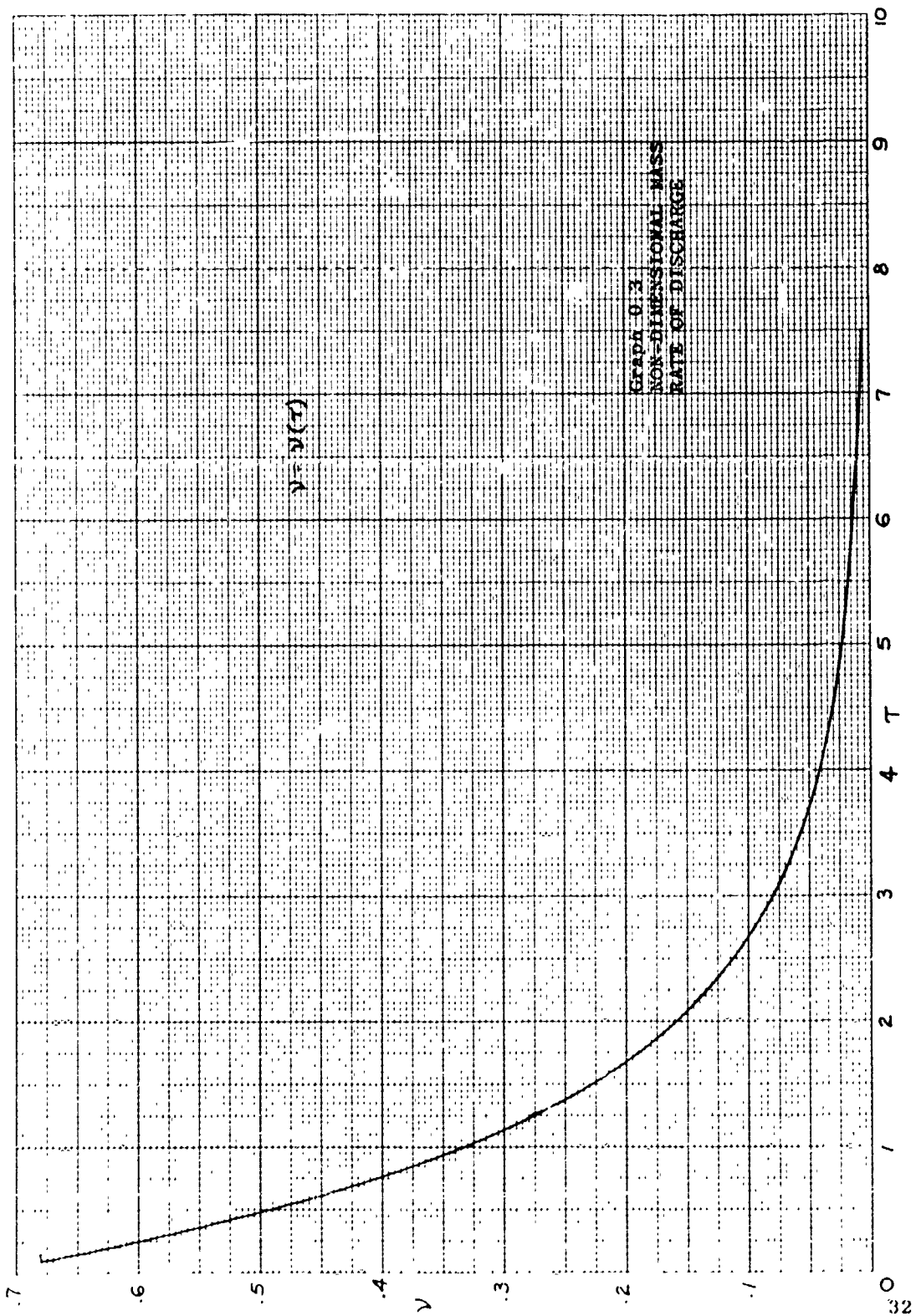
Table 0.7

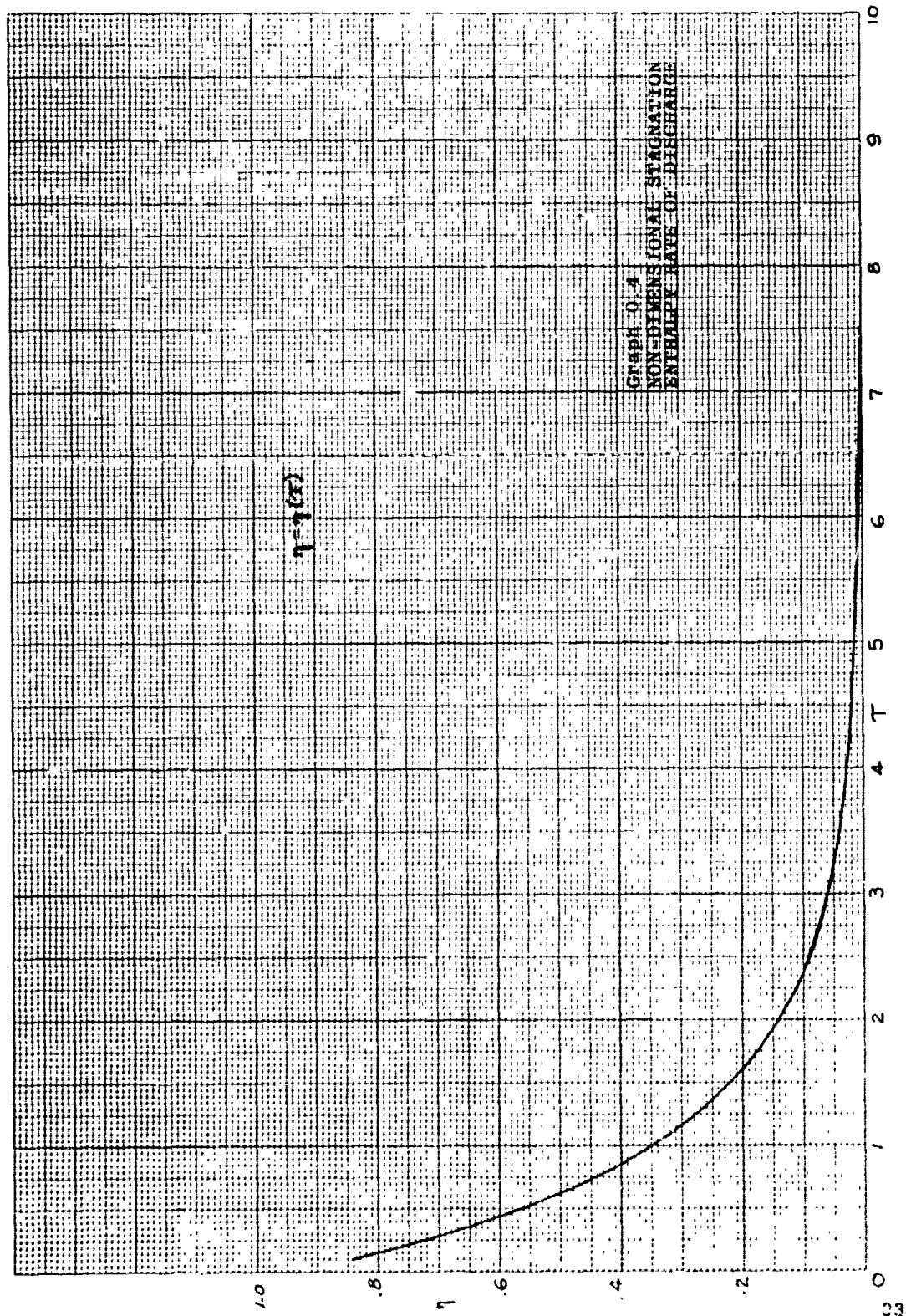




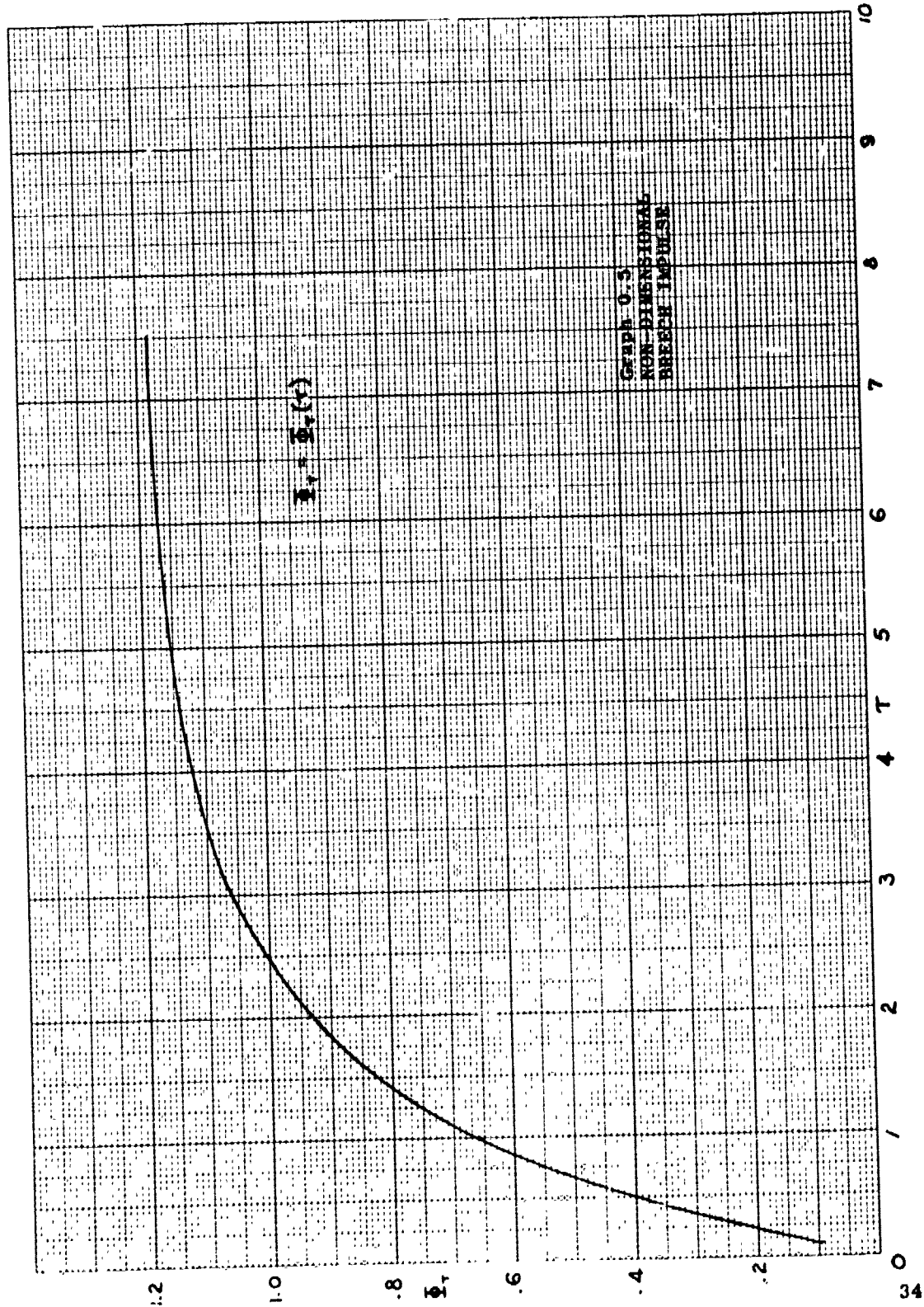
Graph 0.2  
NON-DIMENSIONAL MOMENTUM  
RATE OF DISCHARGE

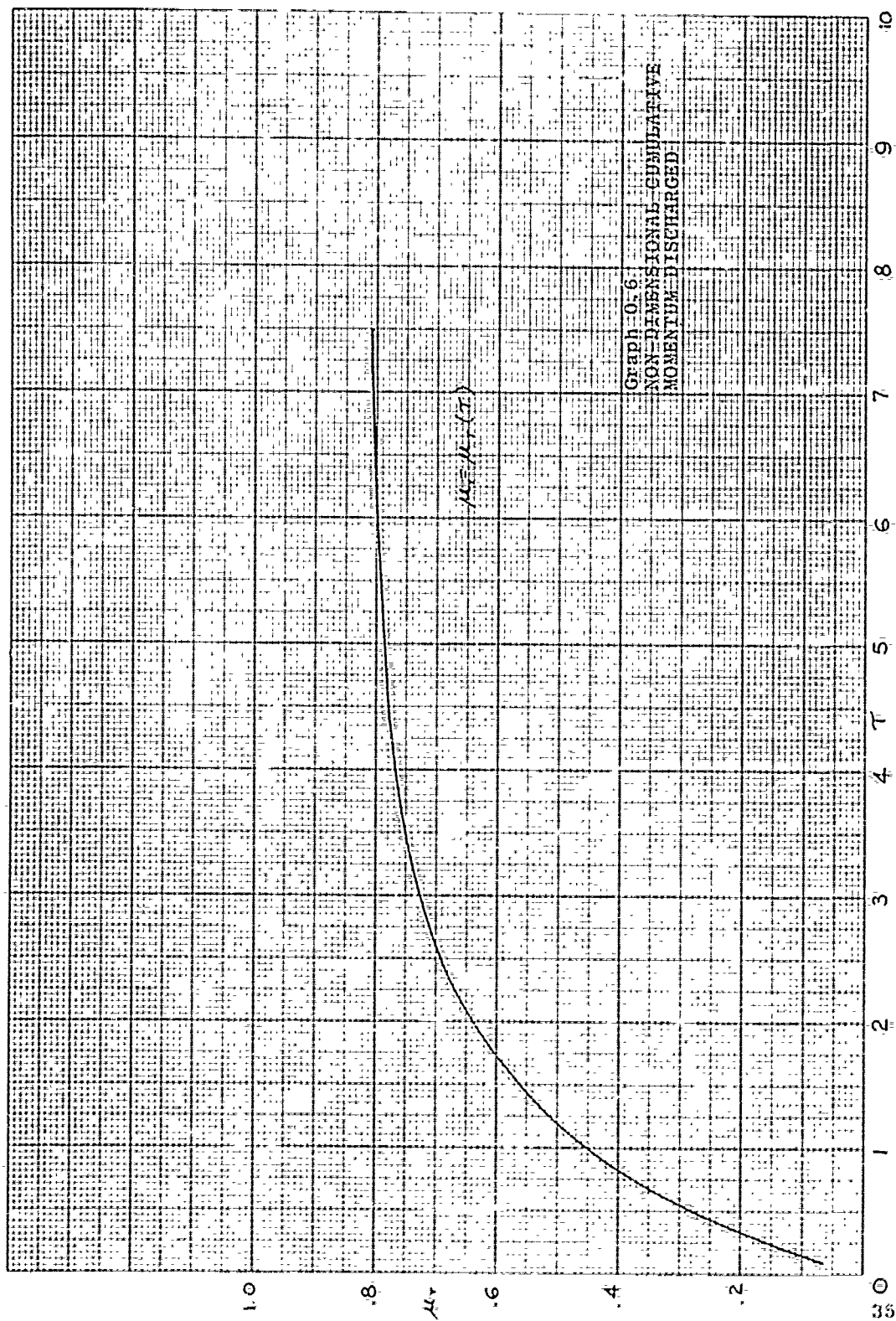
$M = \mu(\tau)$

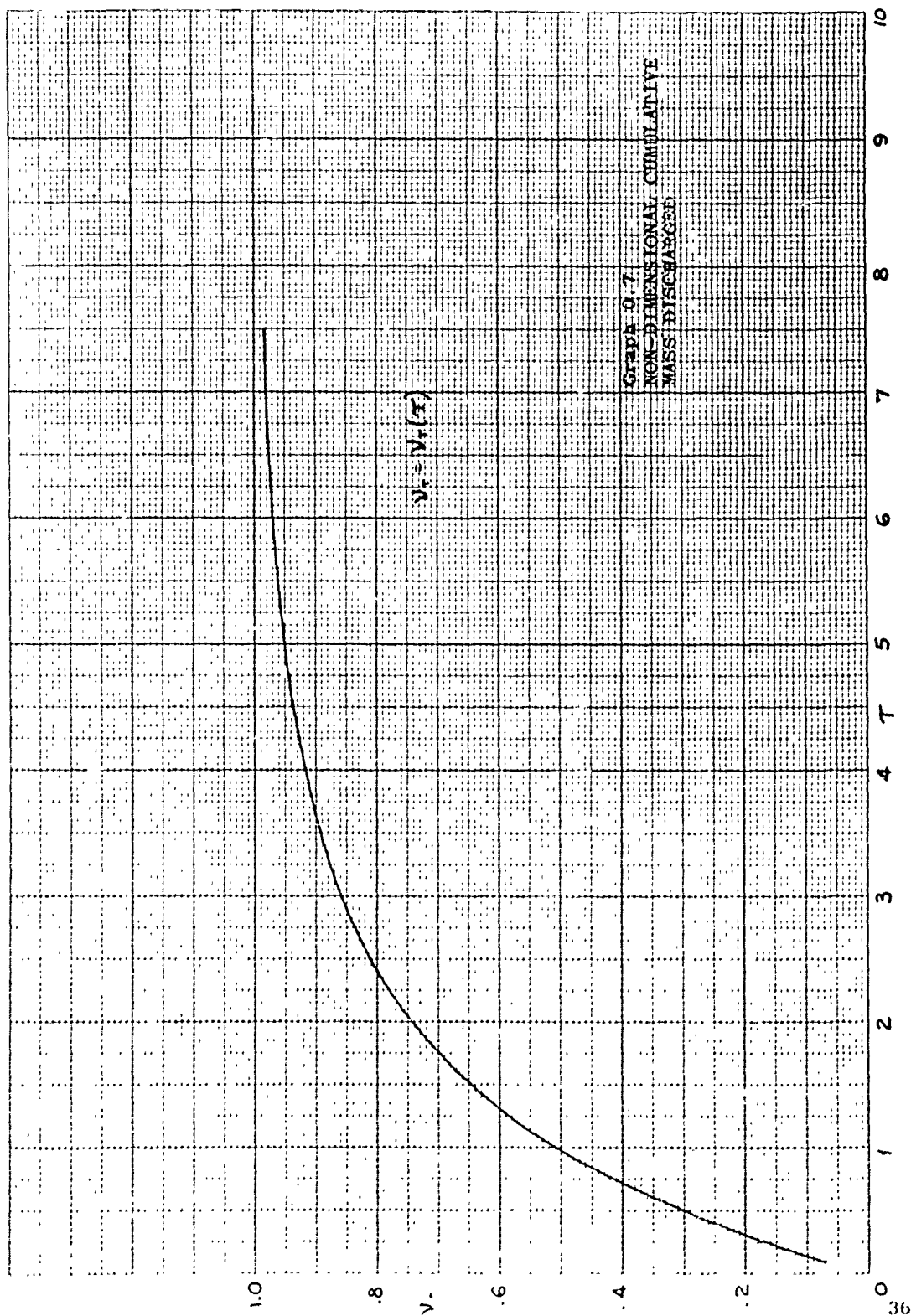


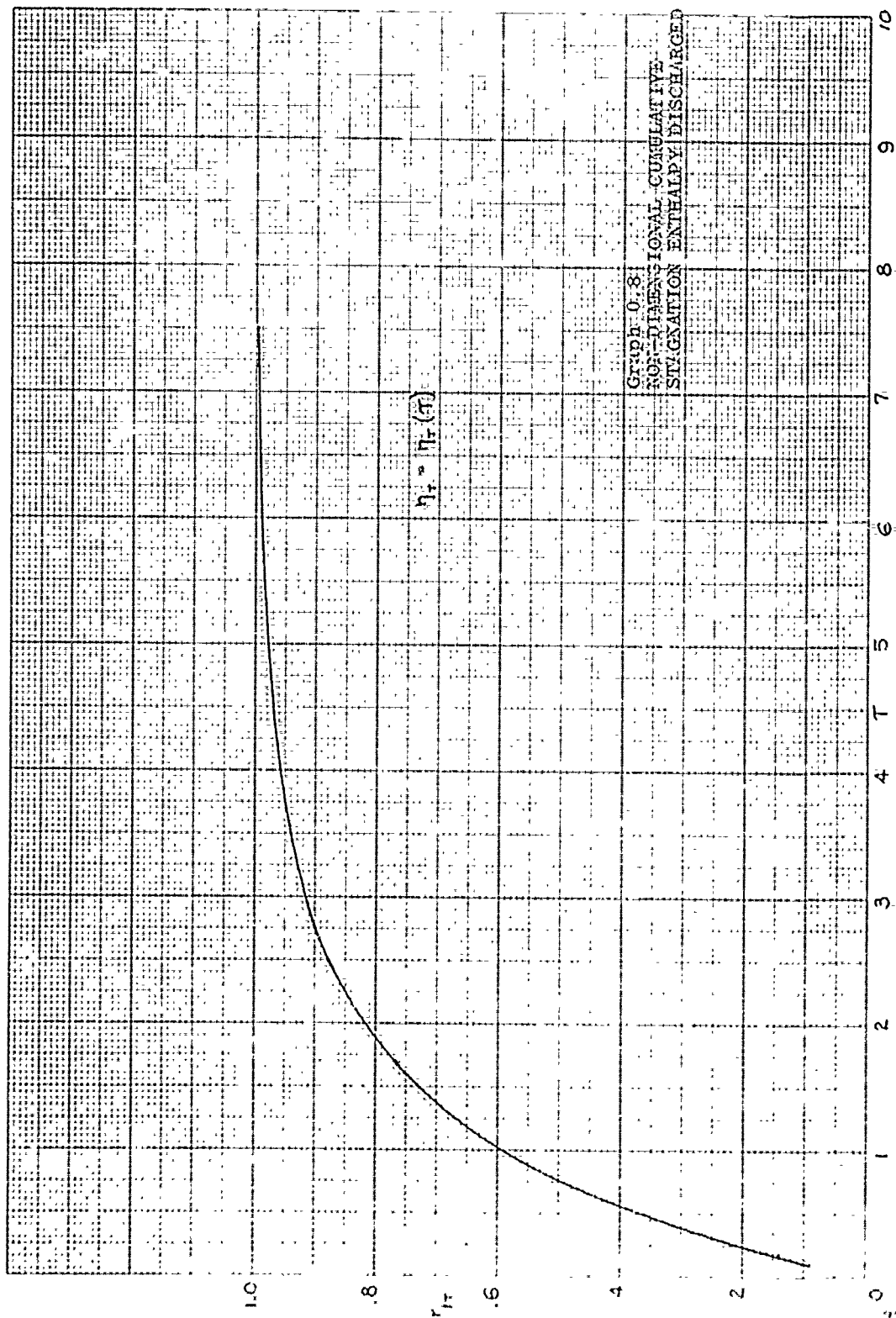


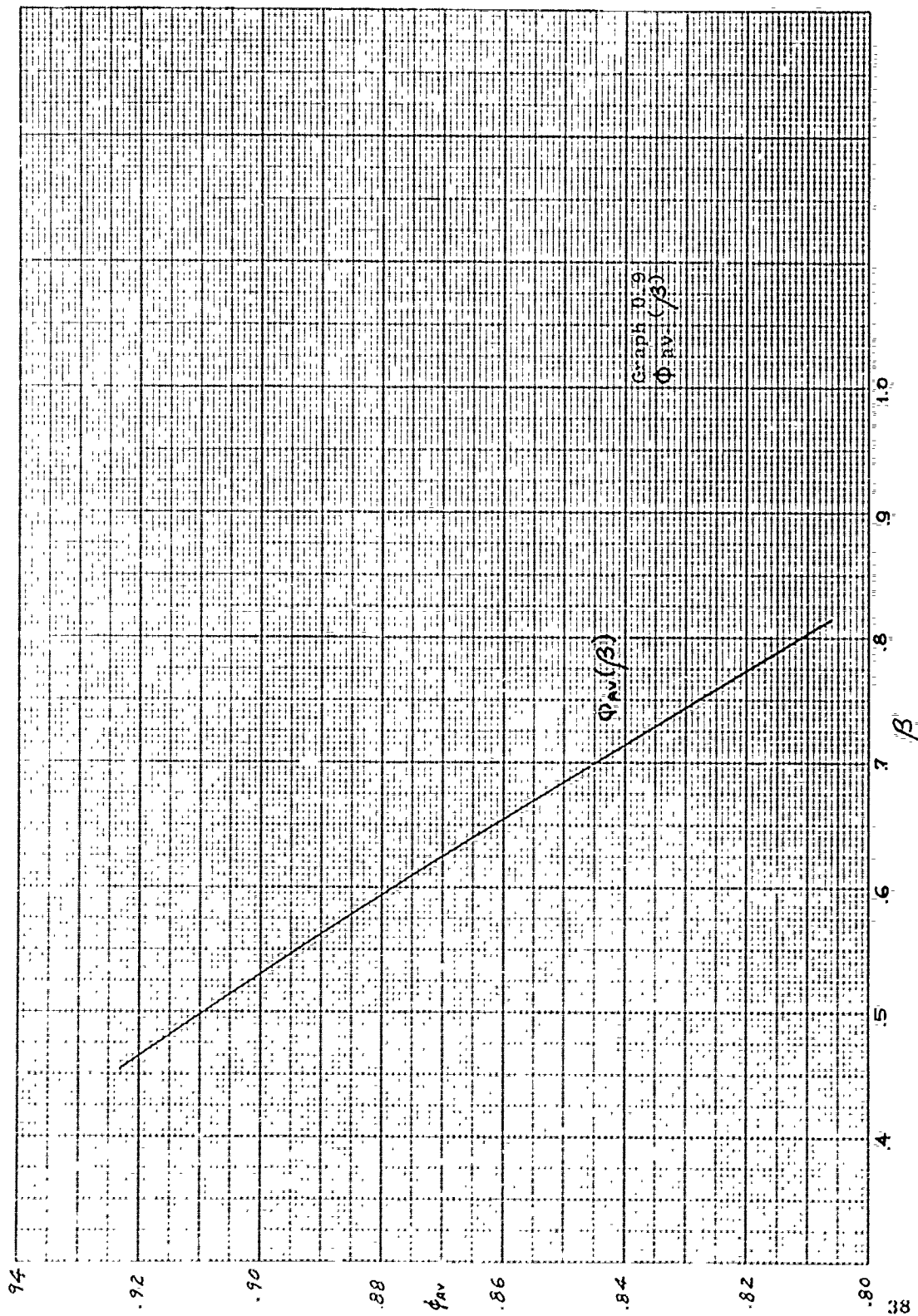


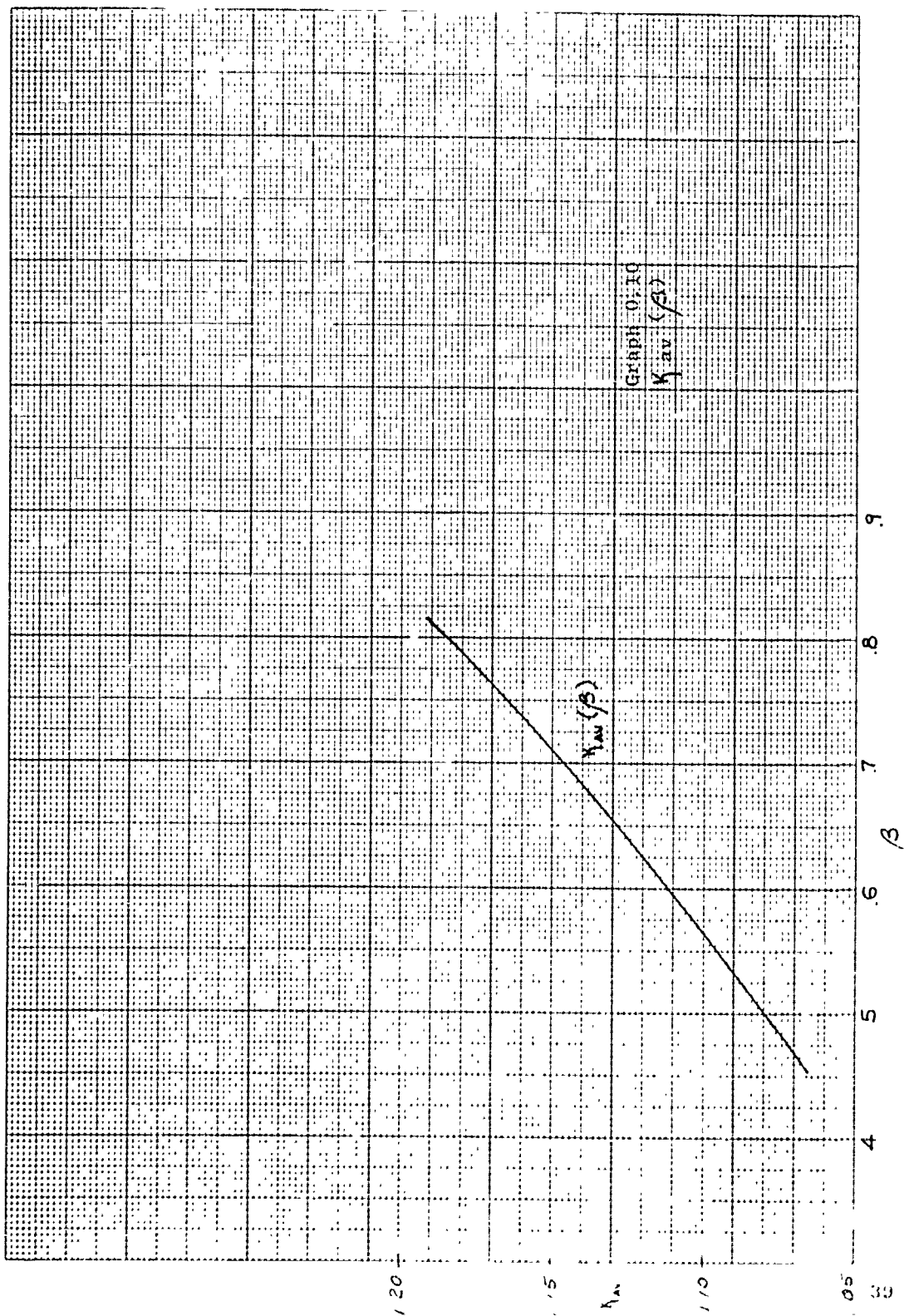


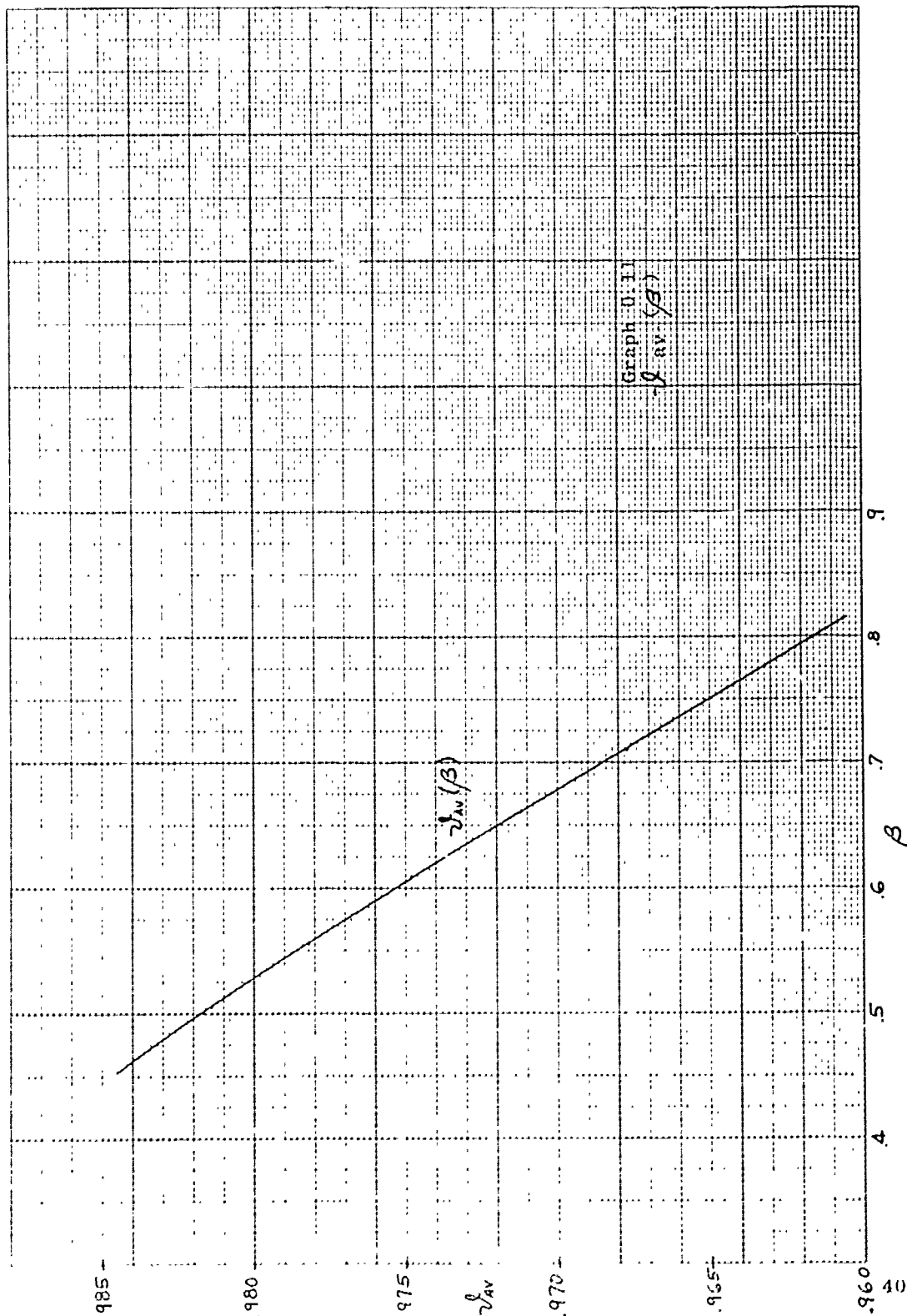




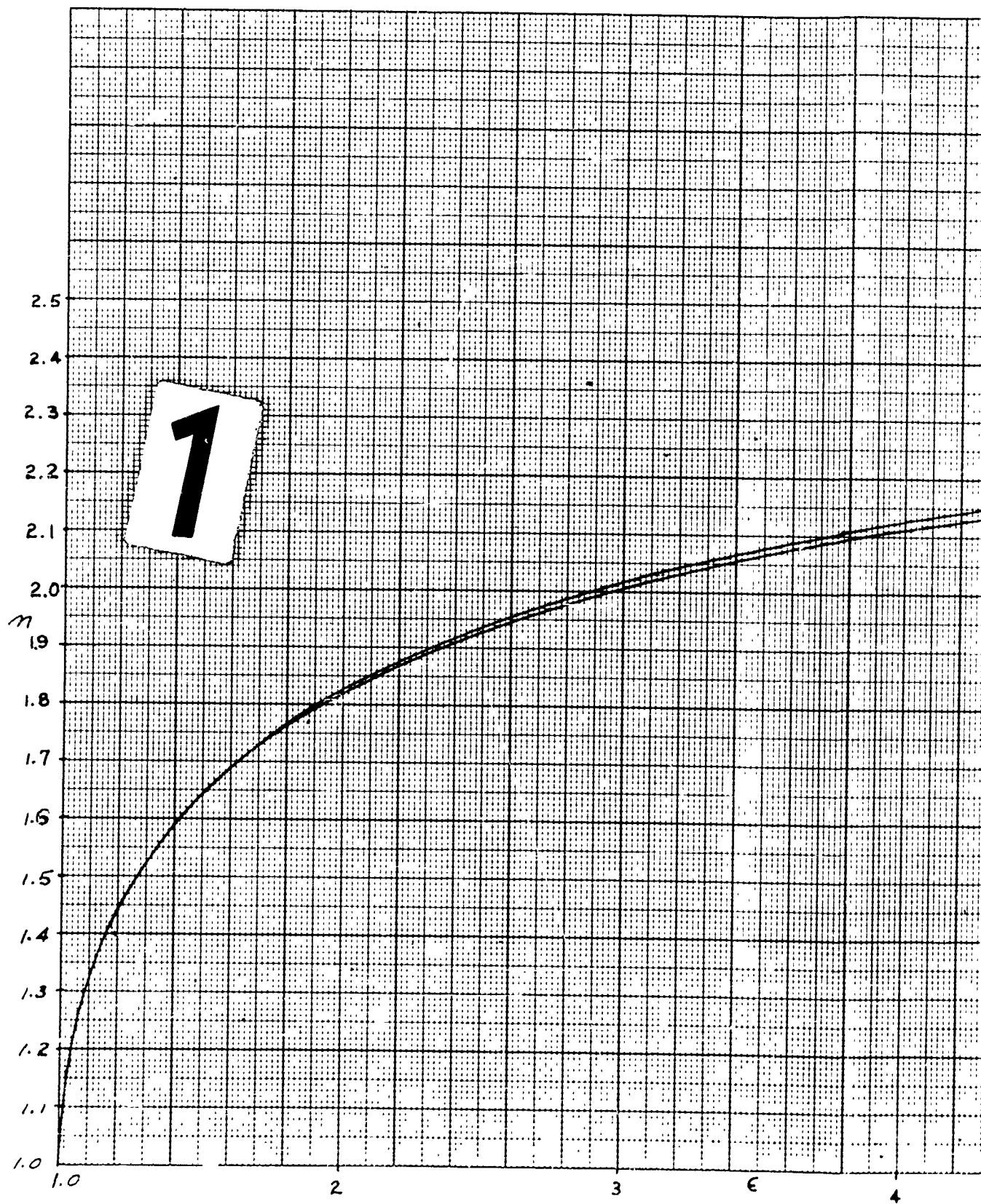




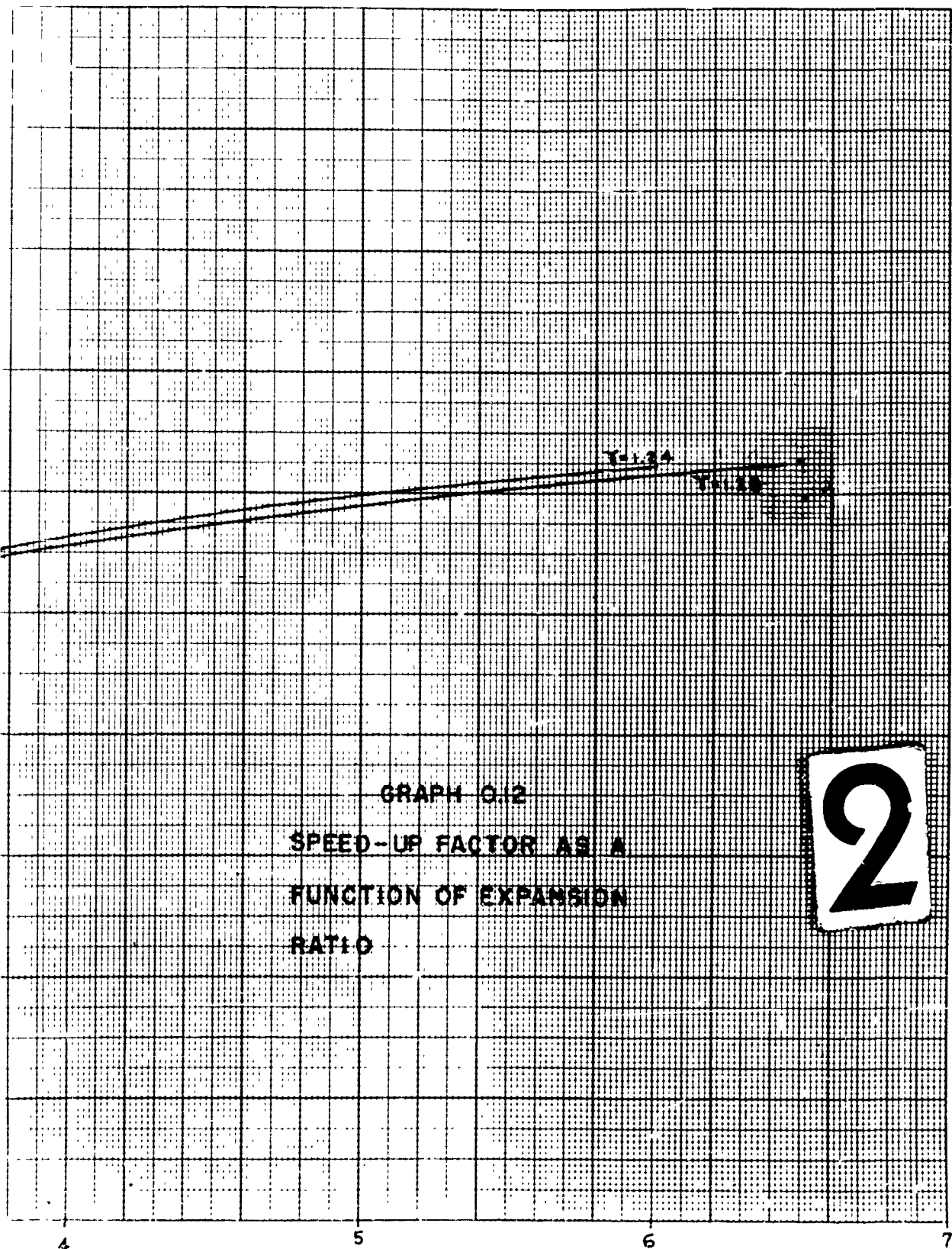












## USE OF DIPARDIP

This program was designed to be used with an interpretive routine for the LGP-30 computer called DICTATOR. Consequently the conventions established for that routine will be followed here.

As explained in the INTRODUCTION, DIPARDIP will compute the various parameters of interest in connection with a particular weapon-brake system during the gas discharge period. These parameters are labeled when printed. A sample format with explanations is shown on the next page.

# DIPARDIP FORMAT

## Energies

### Etu

tot	(total energy available)			
proj	(energy taken by projectile)			
gas, kin	(kinetic energy in gas at t.)			
rec mass	(energy of recoiling parts)			
engrv	(engraving energy)			
gas, therm	(thermal energy remaining in gas at t.)			
av T	(average temperature in gas in tube at t.)			
av p	(average pressure in gas in tube at t.)			
1.	t, sec (time from t.)	P, psi (pressure at the breech)	B, lb f (breech force)	dP/dt, lb f (momentum rate of discharge)
2.	B cml (breech impulse)	P, lb f sec (cumulative momentum discharged)	M, lb m (cumulative mass discharged)	H, Btu (cumulative stagnation enthalpy discharged)
3.	I z, lb f sec (resultant axial impulse)	F z, lb f (axial brake force)	I y, lb f sec (normal impulse)	F y, lb, f (normal brake force)
λ r (closed brakes only)			v eff	ω
				dM/dt, lb m/sec (mass rate of discharge)
				dH/dt, Btu/sec (stagnation enthalpy rate of discharge)
				P-index (momentum index)

To obtain these results, it is necessary to prepare a different type of data tape for each type of brake considered. They are classed as follows:

- Type 1. Closed, asymmetric brakes
- 2. Closed, symmetric brakes
- 3. Open, symmetric brakes
- 4. Closed, free-periphery brakes .

For each of the types, the data pertaining to the weapon and propellant charge must be entered on the data tape as follows:

20000100

$\gamma^*$

R

$e_c$

$e_{ig}$

A

$A_{cnot}$

$\gamma_r$

$M_c$

$M_{ig}$

$M_F$

$M_r$

V

exit' .

The data tapes for each type may be completed as shown below. (Refer to the appropriate appendix for a drawing of the brake )

#### Type 1

20000070'

S01 S11 S21  $\alpha_1$   $\beta_1$  (by rows)

S02 S12 S22  $\alpha_2$   $\beta_2$

S03 S13 S23  $\alpha_3$   $\beta_3$

exit' \*\*

\* All numbers must be written in the "x50" system which is used with the DICTATOR interpreter.

\*\* The "exit' " must be typed after  $\beta_j$  for  $j=1$  or 2 for a

## Type 2

The same data tape format is followed for this type as for type 1, with the exception that  $\beta_j$  is assigned the value 1.5707,  $\pi/2$ .

## Type 3

```
20000090'  
   $\beta_j$  *  
    I  
    Q  
     $z_m$   
     $\alpha_1$   
  exit'
```

## Type 4

In addition to the data prepared for a type 1 brake, the following data should be entered:

```
20000052'      *  
 $\beta_{11}$    $\beta_{21}$    $\beta_{31}$   (by rows)  
 $\beta_{12}$    $\beta_{22}$    $\beta_{32}$   
 $\beta_{13}$    $\beta_{23}$    $\beta_{33}$   
  
  exit' ** .
```

The value of  $\beta_j$  used for a type 1 brake is not used for a type 4. Substitution of 0 for this value is, therefore, recommended in preparing a data tape for a type 4 brake.

---

one or two baffle brake, respectively, i.e., after the last value.

For a two- or three-baffle brake the following must also be typed:

```
10001512'  
8000000(j-1)' .
```

\* op cit

\*\* The "exit' " should be placed after the last  $\beta_{3j}$ .

For each of the four types of brake designs considered, there is an initial program location. Corresponding to each initial location, there is a start compute instruction. These are:

- for type 1. 30001509'
- 2. 30001500'
- 3. 30001000'
- 4. 30001505' .

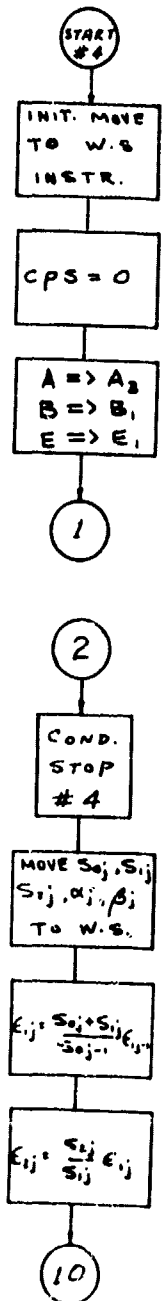
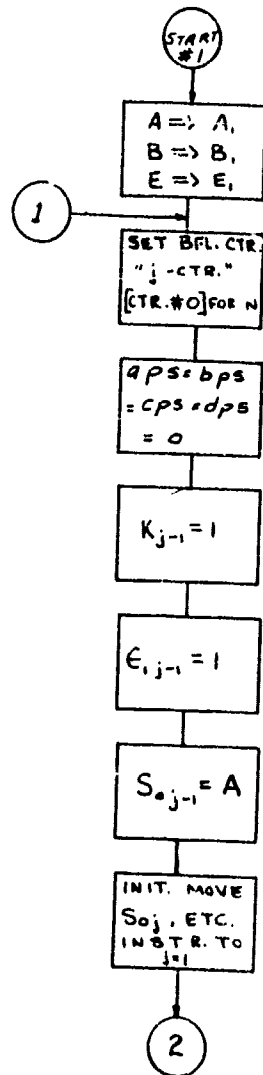
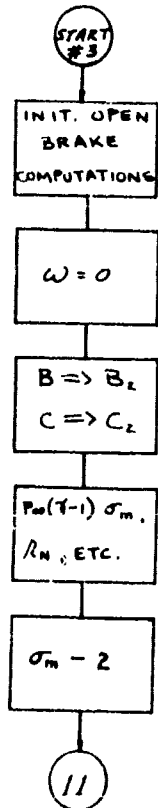
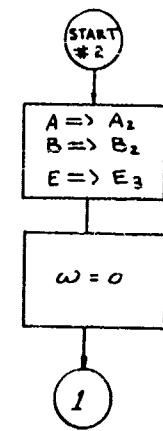
The program uses all breakpoints except 8. Therefore, these must be depressed for uninterrupted operation. If, and only if, the high speed punch is to be used, DICTATOR requires that break point 8 be depressed also.

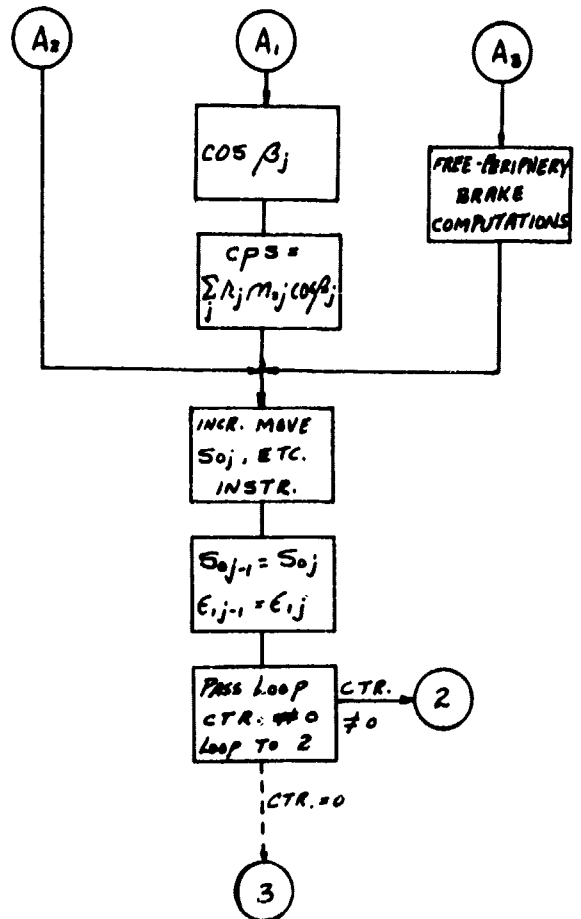
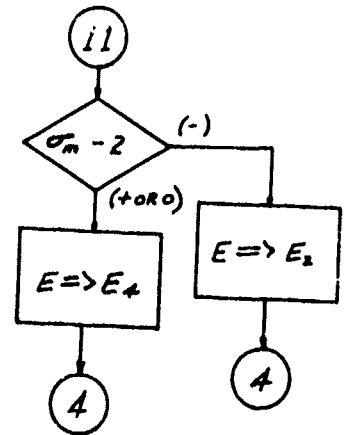
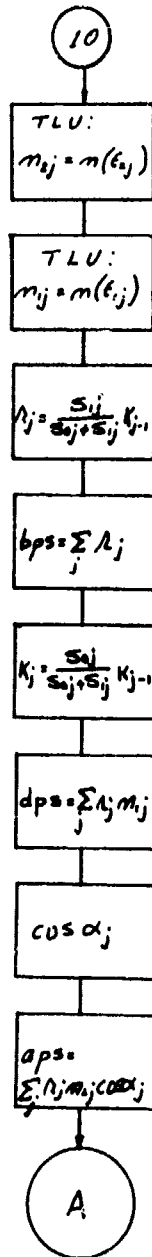
When the break points are not depressed, the computer will stop -- at conditional stop 4 during the computation of the momentum index for closed brakes and prior to printing the parameters for the present value of time, t -- at conditional stop 16 prior to computing the parameters for the next instant in time -- and at stop 32 prior to initializing non-dimensional parameter locations for type 1 brakes.

When used with the high speed punch, the computer takes about twenty minutes to complete the computations for one weapon-brake system.

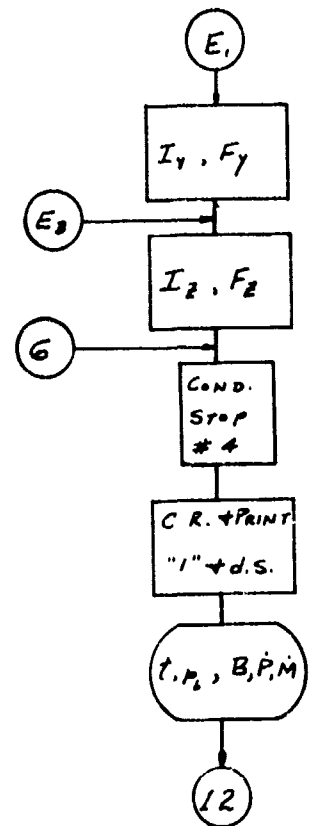
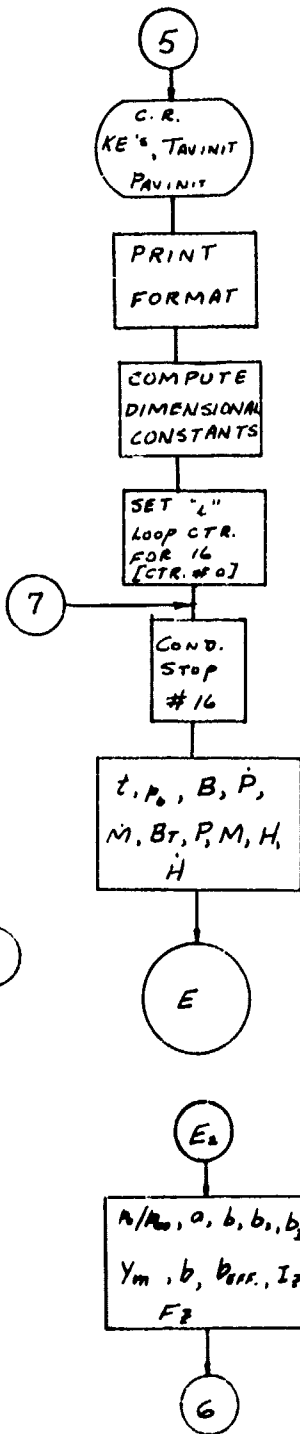
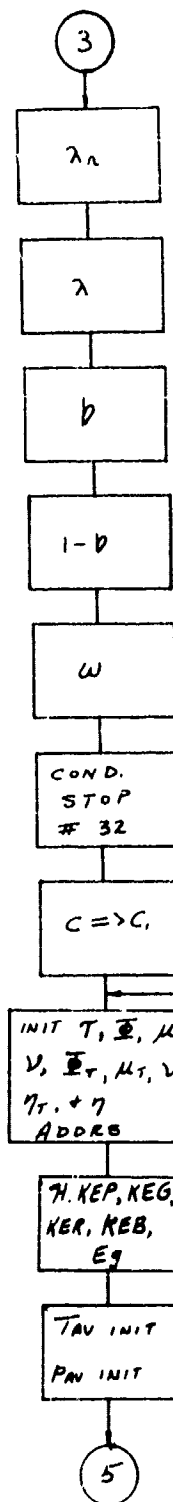
# LOGIC DIAGRAM

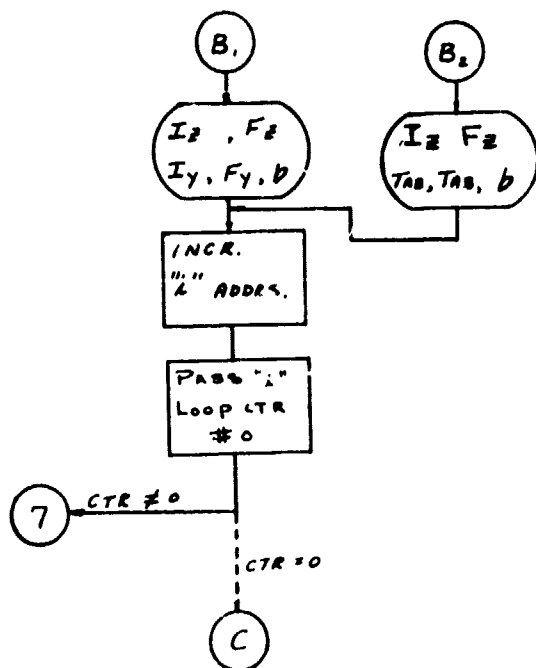
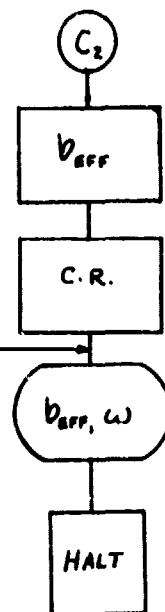
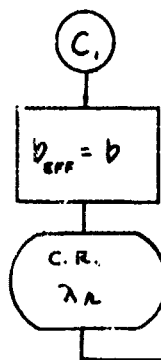
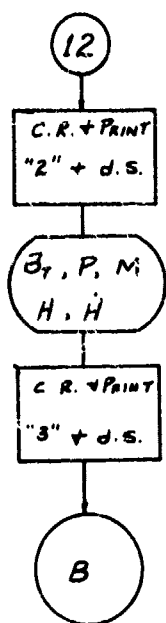
## DIPARDIP



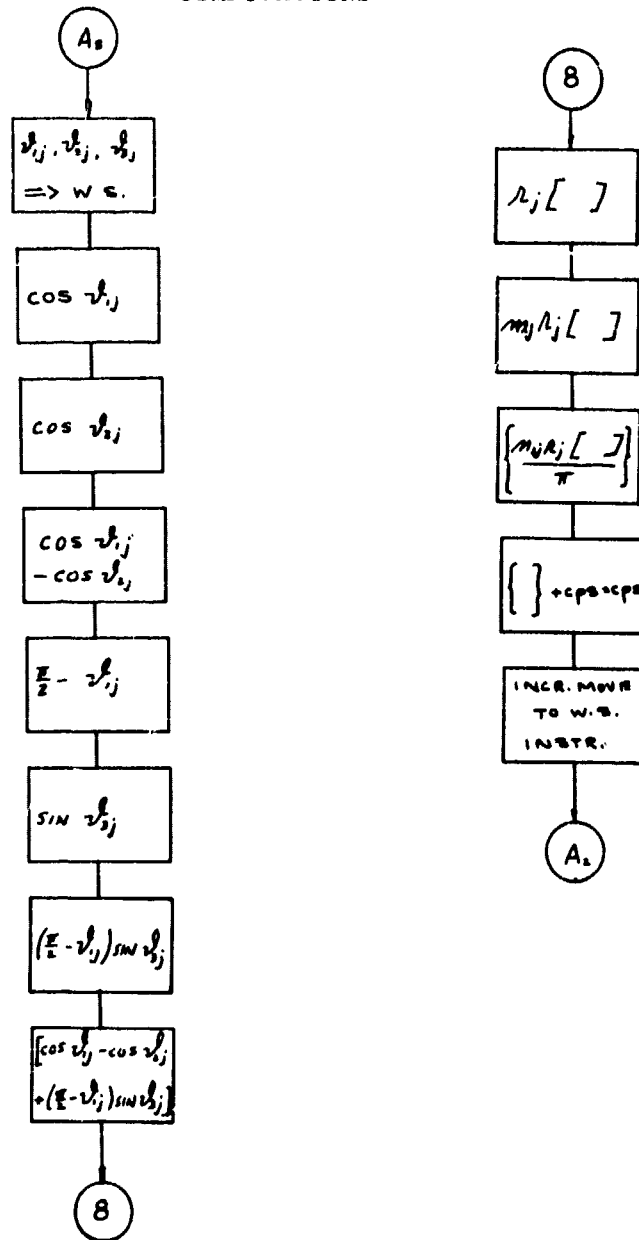




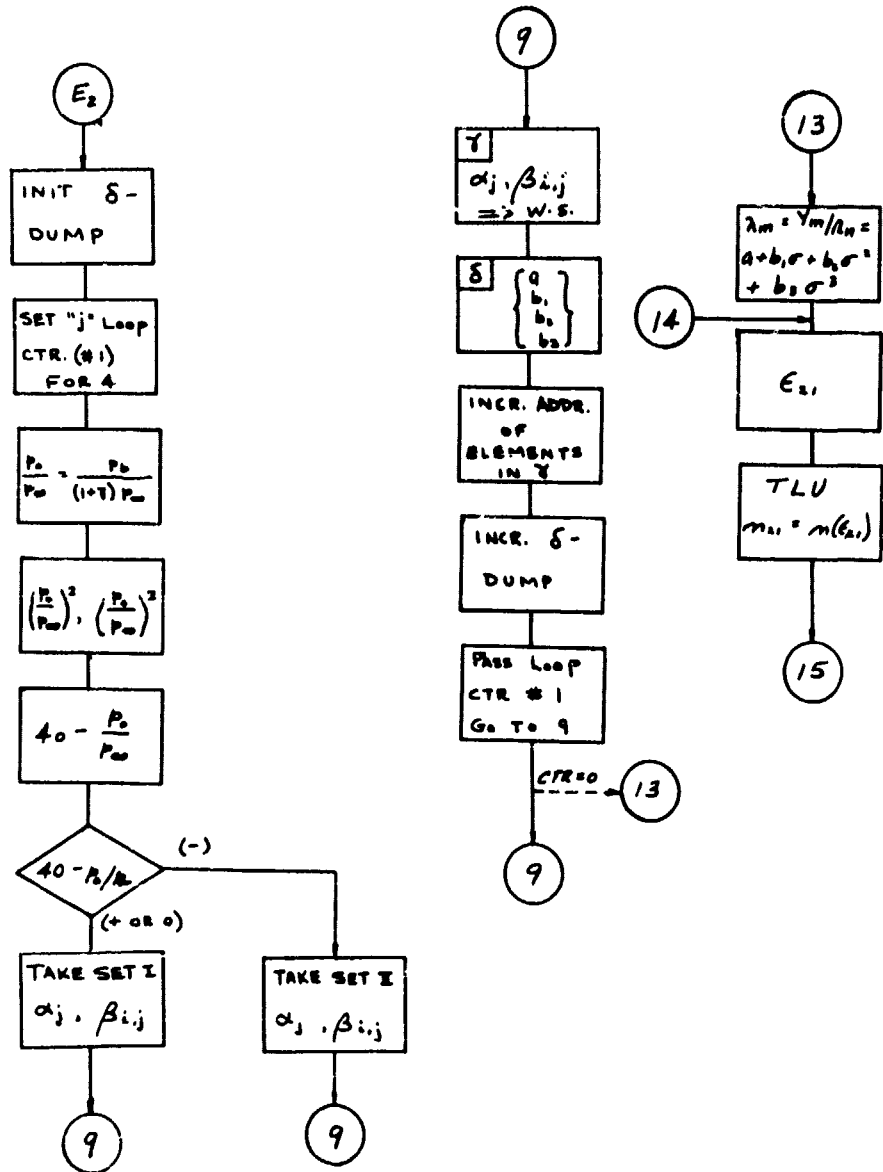


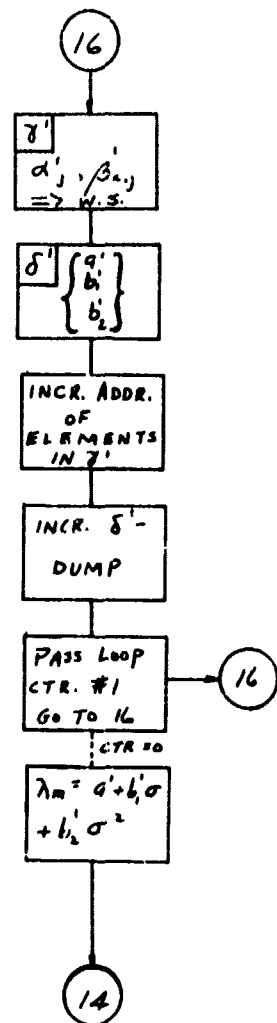
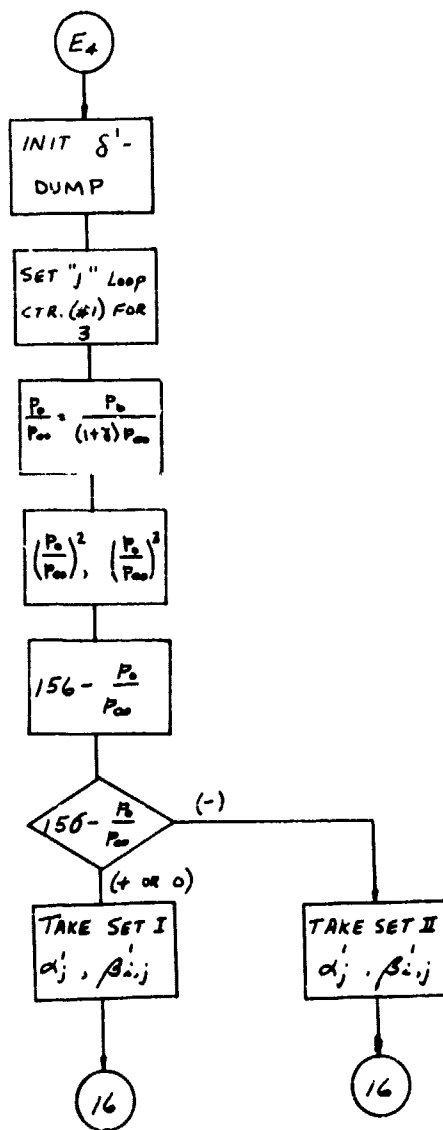


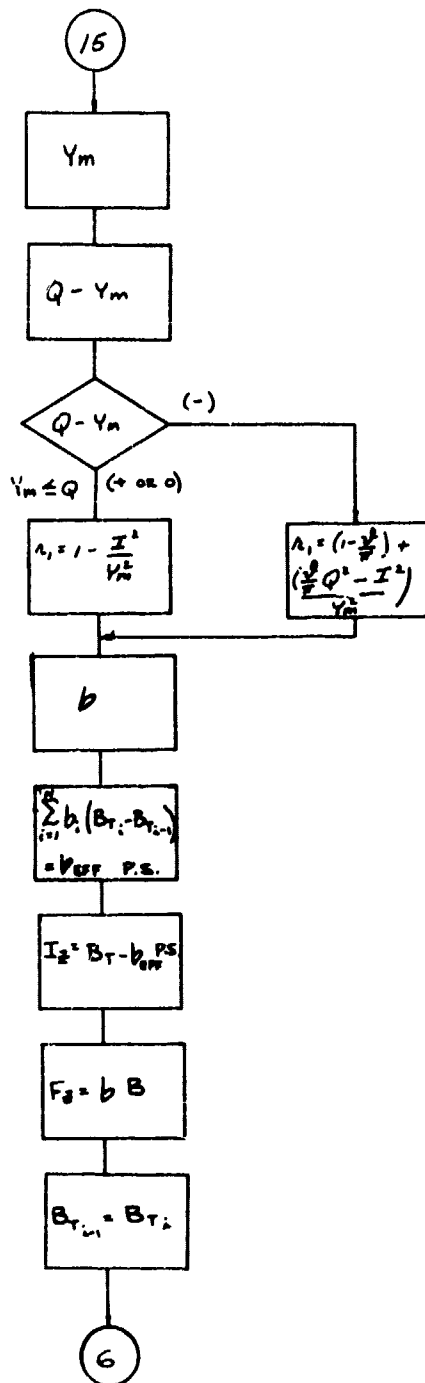
DETAIL LOGIC DIAGRAM FOR  
FREE-PERIPHERY BRAKE  
COMPUTATIONS



DETAIL LOGIC DIAGRAM  
FOR OPEN BRAKE  
COMPUTATIONS







# STORAGE ALLOCATIONS

## General

<u>Locations</u>	<u>Contents</u>
0012-0036	constants
0038-0050	open
0052-0068	$\mathcal{V}_{11} \dots \mathcal{V}_{33}$ , for free-periphery brakes
0070-0098	$S_{01} \dots \beta_3$ , for closed brakes
0090-0098	$\mathcal{V}$ , I, Q, $z_m$ , $\alpha$ , for open brakes
0100-0128	interior ballistic data
0130-0142	constants
0144-0174	$\mathcal{T}$ table
0176-0206	$\Phi$ table
0208-0238	$\mu$ table
0240-0270	$\gamma$ table
0272-0302	$\Phi_r$ table
0304-0334	$\mu_r$ table
0336-0366	$\gamma_r$ table
0368-0398	$\eta_r$ table
0400-0498	working storage
0500-0558	print out
0560	$\dot{P}/B = \mu / \Phi$ = .6808226 for $\gamma = 1.26$
0562-0648	open
0650-0680	$\eta$ table
0682-0738	n table
0740-0796	$\epsilon$ table

<u>Locations</u>	<u>Contents</u>	
0798-0820	$\alpha_0 \dots \beta_{32}$	Set I
0822-0844	$\alpha_0' \dots \beta_{32}'$	Set II
0846-0896	open	
0898-0928	$\alpha_0 \dots \beta_{33}$	Set I
0930-0960	$\alpha_0 \dots \beta_{33}$	Set II
0962-0998	open	
1000-1632	program	

Print Out

<u>Location</u>	<u>Content</u>
0500	t, secs
0502	$p_b$ , psia
0504	B, lb <sub>f</sub>
0506	$\dot{P}$ , lb <sub>f</sub>
0508	$\dot{M}$ , lb <sub>m</sub> /sec
0510	$B_T$ , lb <sub>f</sub> secs
0512	P, lb <sub>f</sub> secs
0514	M, lb <sub>m</sub>
0516	H, Btu
0518	$\dot{H}$ , Btu and $\dot{H}$ , Btu/sec
0520	KEP, Btu
0522	KEG, Btu
0524	KER, Btu
0526	KEB, Btu



<u>Location</u>	<u>Content</u>
0528	$E_g$ , Btu
0530	$T_{av \text{ init}}$ , °R
0532	$P_{av \text{ init}}$ , psia
0534	$1 - \vartheta$
0536	$\vartheta$
0538	$\lambda_r$
0540	$\omega$
0542	$\lambda$
0544	$\sum_i \vartheta_i (B_{Ti} - B_{Ti-1})$ , $\vartheta_{eff}$
0546	$I_z$
0548	$F_z$
0550	$I_y$
0552	$F_y$
0554	open
0556	
0558	

Constants and Internal  
Ballistic Data

<u>Location</u>	<u>Content</u>
0012	0
0014	14.7, $p_{\infty}$
0016	3.141593, $\pi$
0018	40
0020	1.570796, $\pi/2$
0022	1.0495200
0024	-.25021815
0026	-.061082024
0028	.97960297
0030	.10274869
0032	.19109947
0034	156
0036	1.33, $f_3$
.....	
0100	$\gamma$
0102	R
0104	$e_c$
0106	$e_{ig}$
0108	A
0110	$A_{cnct}$
0112	$\mathcal{V}_T$
0114	$M_c$
0116	$M_{ig}$
0118	$M_p$

<u>Location</u>	<u>Content</u>
0120	$M_r$
0122	$v_o$
0124	$f_o$
0126	$f_1$
0128	$f_2$
0130	1
0132	2
0134	0.18, tube coefficient of friction
0136	32.17, g
0138	777.5, J
0140	3
0142	12

Closed Brake Data  
Storage

<u>Location</u>	<u>Content</u>
0070	$S_{01}$ , in <sup>2</sup>
0072	$S_{11}$ , in <sup>2</sup>
0074	$S_{21}$ , in <sup>2</sup>
0076	$\alpha_1$ , radians
0078	$\beta_1$ , radians
0080	$S_{02}$ , in <sup>2</sup>
0082	$S_{12}$ , in <sup>2</sup>
0084	$S_{22}$ , in <sup>2</sup>
0086	$\alpha_2$ , radians
0088	$\beta_2$ , radians
0090	$S_{03}$ , in <sup>2</sup>
0092	$S_{13}$ , in <sup>3</sup>
0094	$S_{23}$ , in <sup>2</sup>
0096	$\alpha_3$ , radians
0098	$\beta_3$ , radians

Additional Closed Brake Data  
Storage for Free-Periphery Designs

<u>Location</u>	<u>Content</u>
0052	$\psi_{11}$ , radians
0054	$\psi_{21}$
0056	$\psi_{31}$
0058	$\psi_{12}$
0060	$\psi_{22}$
0062	$\psi_{32}$
0064	$\psi_{13}$
0066	$\psi_{23}$
0068	$\psi_{33}$

Open Brake Data  
Storage

<u>Location</u>	<u>Content</u>
0090	$\psi$ , radians
0092	I , inches
0094	Q , inches
0096	$z_m$ , inches
0098	$\alpha_1$ , radians

# General Working Storage

<u>Location</u>	<u>Content</u>
0400	$\beta = \frac{v_o}{a_{av} \text{ init}}$
0402	$p_b \text{ init}$
0404	$A p_b \text{ init}$
0406	$A g p_b \text{ init}$
0408	$a_{av} \text{ init}$
0410	$a_b \text{ init}$
0412	$a_b \text{ init } M_T$
0414	$\frac{M_T a_b \text{ init}}{g} = \frac{A p_b \text{ init}}{\alpha_T}$
0416	$\frac{A g p_b \text{ init}}{a_b \text{ init}}$
0418	$\alpha_T = \frac{A g p_b \text{ init}}{M_T a_b \text{ init}}$
0420	$\beta^2$
0422	open
0424	open
0426	$\phi_{av}$
0428	$\nu_{av}$
0430	$\eta_{av}$
0432	$\left(\frac{v_r}{v_o}\right)^2$
0434	$\frac{v_o^2}{2gJ}$

<u>Location</u>	<u>Content</u>
0436	$M_{\tau}$
0438	$\frac{M_{\tau}}{2} , \left( 1 + \frac{v_r}{v_o} \right)$
0440	$\frac{M_{\tau}}{2} + M_p , \frac{v_r}{v_o}$
0442	$\frac{1 + \frac{v_r}{v_o}}{3} , \frac{\left( \frac{v_r}{v_o} \right)^2 + \left( 1 + \frac{v_r}{v_o} \right)^2}{3} ,$ $\frac{\left( \frac{v_r}{v_o} \right)^2 + \left( 1 + \frac{v_r}{v_o} \right)^2 - \left( \frac{v_r}{v_o} \right) \left( 1 + \frac{v_r}{v_o} \right)}{3}$
0444	$(\gamma - 1) E_g J$
0446	$\gamma_g R$
0448	$E_g \alpha_{\tau}$
0450	$I^2$
0452	$\frac{\sqrt{2}}{\pi} Q^2 - I^2$
0454	$1 - \cos \alpha_1$
- - - - -	
0520	$(p_o/p_{\infty})^2$
0522	$(p_o/p_{\infty})^3$

Closed Brake Working Storage

<u>Location</u>	<u>Content</u>
0400	$aps = \sum_j r_j n_{2j} \cos \alpha_j$
0402	$bps = \sum_j r_j$
0404	$cps = \sum_j r_j n_{2j} \cos \beta_j$
0406	$dps = \sum_j r_j n_{1j}$
0408	space
0410	$K_{j-1}$
0412	$\epsilon_{1j-1}$
0414	$s_{0j-1}$
0416	$s_{0j} + s_{1j}$
0418	$\epsilon_{1j}$
0420	$s_{0j}$
0422	$s_{1j}$
0424	$s_{2j}$
0426	$\alpha_j$
0428	$\beta_j$
0430	$\epsilon_{2j}$
0432	$n_{1j}$
0434	$n_{2j}$
0436	$r_j$
0438	$n_{1N} (1 - \sum_{j=1}^N r_j)$



LocationContent

0440

$$\nu_{1j}^l$$

0442

$$\nu_{2j}^l$$

0444

$$\nu_{3j}^l$$

0446

$$\cos \nu_{1j}^l, \cos \nu_{1j}^l - \cos \nu_{2j}^l$$

0448

$$\pi/2 - \nu_{1j}^l,$$

$$n_{2j} r_j [\cos \nu_{1j}^l - \cos \nu_{2j}^l + (\pi/2 - \nu_{1j}^l) \cdot \sin \nu_{3j}^l]$$

Open Brake Working Storage

<u>Location</u>	<u>Content</u>
0450	$I^2$
0452	$\frac{v^l}{\pi} Q^2 - I^2$
0454	$1 - \cos \alpha_1$
0456	open
0458	$r_N = \sqrt{\frac{A}{\pi}}$
0460	$\alpha_j$
0462	$\beta_{1j}$
0464	$\beta_{2j}$
0466	$\beta_{3j}$
0468	a
0470	$b_1$
0472	$b_2$
0474	$b_3$
0476	$\sigma_m = \frac{z_m}{r_N}$
0478	$\sigma_m^2$
0480	$\sigma_m^3$
0482	$(1 + \gamma) p_\infty$
0484	$\frac{v^l}{\pi}$
0486	$1 - \frac{v^l}{\pi}$
0488	$(B_T)_{1-1}$

<u>Location</u>	<u>Content</u>
0490	$\frac{y_m}{r_N}, y_m$
0492	$1 + \frac{\sqrt{q}}{\pi} \left( \frac{y_m}{r_N} \right)^2 = \epsilon_{21}$
0494	$n_{21} = n(\epsilon_{21})$
0496	$p_o / p_\infty$
0498	$r_1$

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR: MUZZLE BRAKES						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY: G. SCHLENKER				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
1000	25	50	75			15	0098	0000	START E. OPEN BRAKE		
01	26	51	76	2	0130		0000	0454	COS $\alpha_1$		
02	27	52	77			4	1417	1421	$B \Rightarrow B_1$		
03	28	53	78			4	1437	1444	<input checked="" type="checkbox"/> $C \Rightarrow C_1$		
04	29	54	79	6	0002		0012	0540	$\omega = 0$		
05	30	55	80	6	0002		0012	0488	$(B_1)_{1-1} = 0$		
06	31	56	81	6	0002		0012	0544	$P_{BR} P_{B_1} = 0$		
07	32	57	82	3	0094		0094	0452	<input checked="" type="checkbox"/> $Q^1$		
08	33	58	83	3	0092		0092	0450	$I^1$		
09	34	59	84			1	0000	1628			
1010	35	60	85	1	0130		0100	0000	$1 + T$		
11	36	61	86	3	0000		0014	0482	<input checked="" type="checkbox"/> $(1 + T) P_0$		
12	37	62	87	4	0108		0016	0000	$Q / T$		
13	38	63	88			13	0000	0458	$R_N$		
14	39	64	89	4	0096		0000	0476	$\sigma_m$		
15	40	65	90	3	0000		0000	0478	<input checked="" type="checkbox"/> $\sigma_m^1$		
16	41	66	91	3	0000		0476	0480	$\sigma_m^3$		
17	42	67	92	2	0476		0132	0000	$\sigma_m - 2$		
18	43	68	93			2	1585	1019	FOR $\sigma_m^E 2$ , $\Rightarrow 1585$		
1019	44	69	94			4	1397	1451	<input checked="" type="checkbox"/> $E \Rightarrow E_1$		
1020	45	70	95			6	1386	0144	INITIALIZE T FOR t		
21	46	71	96			5	1387	0176	FOR $P_0$		
22	47	72	97			5	1388	0176	FOR B		
23	48	73	98			5	1389	0208	<input checked="" type="checkbox"/> FOR P		
1021	49	74	99			5	1390	0240	<input checked="" type="checkbox"/> FOR M		

LGP-30 CODING SHEET (Dictator Format)															
PREPARED FOR:							JOB NO.			PROGRAM NO.		PAGE NO. 2		NO. OF PAGES 26	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:			DATE RUN:		SUPERSEDED BY PROGRAM NO.		
PROBLEM:															
LOCATION (MAKE APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS						
00	1025	50	75			5	1391	0272	INITIALIZE $E_r$ FOR $B_r$						
01	26	51	76			5	1392	0304	$\mu_r$ FOR P						
02	27	52	77			5	1393	0336	$V_r$ FOR M						
03	28	53	78			5	1394	0368	X $\eta_r$ FOR H						
04	29	54	79			5	1395	0650	$\eta$ FOR H						
05	30	55	80	3	0104		0114	0518	$H_a$						
06	31	56	81	3	0106		0116	0000	$H_g$						
07	32	57	82	1	0000		0518	0518	X $H$						
08	33	58	83	3	0122		0122	0000	$V_a^2$						
09	34	59	84	4	0000		0132	0000	$V_a^2/2$						
10	35	60	85	4	0000		0136	0000	$V_a^2/2g$						
11	36	61	86	4	0000		0138	0434	X $V_a^2/2gJ$						
12	37	62	87	3	0000		0118	0520	K.E.P.						
13	38	63	88	1	0114		0116	0436	$M_r$						
14	39	64	89	4	0000		0132	0438	$M_r/2$						
15	40	65	90	1	0000		0118	0440	X $M_r/2 + M_p$						
16	41	66	91	1	0438		0120	0000	$M_r/2 + M_a$						
17	42	67	92	4	0440		0000	0440	$V_a/V_a$						
18	43	68	93	1	0000		0130	0438	$(1 + V_a/V_a)$						
19	44	69	94	3	0000		0000	0000	X $(1 + V_a/V_a)^2$						
20	45	70	95	4	0000		0140	0442	$\frac{1}{2}(1 + V_a/V_a)^2$						
21	46	71	96	3	0440		0440	0432	$(V_a/V_a)^2$						
22	47	72	97	1	0000		0442	0442	$(V_a/V_a)^2 + \frac{1}{2}(1 + V_a/V_a)^2$						
23	48	73	98	5	0438		0440	0000	X $-(V_a/V_a)(1 + V_a/V_a)$						
24	1049	74	99	1	0000		0442	0442							

LGP-30 CODING SHEET (Dictator Format)													
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. 3		NO. OF PAGES 26	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:													
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS				
00	25	1050	75	3	0000		0436	0000					
01	26	51	76	3	0000		0434	0522	K.E.G.				
02	27	52	77	3	0432		0434	0000	$V_n^2 / 2gJ$				
03	28	53	78	3	0000		0120	0524	X K.E.R.				
04	29	54	79	3	0134		0110	0000	.180 CMIT				
05	30	55	80	4	0000		0108	0000	.180 CMIT / 0				
06	31	56	81	3	0000		0520	0526	K.E.B.				
07	32	57	82	1	0000		0524	0000	X				
08	33	58	83	1	0000		0522	0000					
09	34	59	84	1	0000		0520	0000	$\Sigma$ K.E. 5				
10	35	60	85	2	0518		0000	0528	Eg				
11	36	61	86	2	0100		0130	0000	X				
12	37	62	87	3	0000		0528	0000					
13	38	63	88	3	0000		0138	0444	(3-1) Eg J/R				
14	39	64	89	4	0000		0102	0000					
15	40	65	90	4	0000		0436	0530	X TAV INIT				
16	41	66	91	3	0142		0444	0000					
17	42	67	92	4	0000		0112	0532	TAV INIT				
18	43	68	93				8009	0016	C.R.				
19	44	69	94					0008	X U.C.				
20	45	70	95					0037	E				
21	46	71	96					0025	N				
22	47	72	97					0037	E				
23	48	73	98					0013	X R				
24	49	1074	99				8009	0046	G				

## LGP-30 CODING SHEET (Dictator Format)

PREPARED FOR:	JOB NO.	PROGRAM NO.	PAGE NO. 4	NO. OF PAGES 26
PROGRAM PREPARED BY:	PROGRAM CHECKED BY:	DATE PREPARED:	DATE RUN:	SUPERSEDED BY PROGRAM NO.

PROBLEM:

LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS
00	25	50	1075				8009	0017	I
01	26	51	76					0037	E
02	27	52	77					0061	S
03	28	53	78					0024	X TAB
04	29	54	79					0005	B
05	30	55	80					0004	L.C.
06	31	56	81					0045	t
07	32	57	82					0041	X u
08	33	58	83					0016	C.R.
09	34	59	84					0045	t
10	35	60	85					0035	o
11	36	61	86					0045	X t
12	37	62	87				8009	0024	TAB
13	38	63	88			18	0518	0518	H
14	39	64	89				8009	0016	C.R.
15	40	65	90					0033	X P
16	41	66	91					0013	A
17	42	67	92					0035	o
18	43	68	93					0050	j
19	44	69	94				8009	0024	X TAB
20	45	70	95			18	0520	0520	K.F.B.
21	46	71	96				8009	0016	C.R.
22	47	72	97				8009	0046	j
23	48	73	98				8009	0057	X A
24	49	74	1099				8009	0061	S

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
1100	25	50	75				8009	0027			
01	26	51	76					0003	SP.		
02	27	52	77					0054	K		
03	28	53	78					0017	X I		
04	29	54	79					0025	N		
05	30	55	80				8009	0024	TAB		
06	31	56	81			18	0522	0522	K.E.G.		
07	32	57	82				8009	0016	X C.R.		
08	33	58	83					0013	R		
09	34	59	84					0037	E		
10	35	60	85					0053	C		
11	36	61	86					0003	X SP.		
12	37	62	87					0029	M		
13	38	63	88					0057	A		
14	39	64	89					0061	S		
15	40	65	90					0061	X S		
16	41	66	91				8009	0024	TAB		
17	42	67	92			18	0524	0524	K.E.R.		
18	43	68	93				8009	0016	C.R.		
19	44	69	94					0037	X E		
20	45	70	95					0025	N		
21	46	71	96					0046	G		
22	47	72	97					0013	R		
23	48	73	98					0031	X V		
1124	49	74	99				8009	0024	TAB		



LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	1125	50	75			18	0526	0526	K.E. B.		
01	26	51	76				8009	0016	C.R.		
02	27	52	77					0046	G		
03	28	53	78					0057	X A		
04	29	54	79					0061	S		
05	30	55	80					0027	.		
06	31	56	81					0003	SP		
07	32	57	82					0045	X T		
08	33	58	83					0049	H		
09	34	59	84					0037	E		
10	35	60	85					0013	R		
11	36	61	86					0029	X M		
12	37	62	87				8009	0024	TAB		
13	38	63	88			18	0528	0528	Eg		
14	39	64	89				8009	0016	C.R.		
15	40	65	90					0016	X C.R.		
16	41	66	91					0057	A		
17	42	67	92					0031	V		
18	43	68	93					0003	SP		
19	44	69	94					0008	X U.C.		
20	45	70	95					0045	T		
21	46	71	96					0004	L.C.		
22	47	72	97				8009	0024	TAB		
23	48	73	98			18	0530	0530	X TAN INIT		
24	1149	74	99				8009	0016	C.R.		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MAKE APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS		
00	25	1150	75				8009	0057	A		
01	26	51	76					0031	V		
02	27	52	77					0003	SP		
03	28	53	78					0033	P		
04	29	54	79				8009	0024	TAB		
05	30	55	80			18	0532	0532	Fav INIT		
06	31	56	81				8009	0016	C.B.		
07	32	57	82					0016	C.B.		
08	33	58	83					0006	I FORMAT		
09	34	59	84					0003	SP		
10	35	60	85					0003	SP		
11	36	61	86					0045	t		
12	37	62	87					0027	.		
13	38	63	88					0003	SP		
14	39	64	89					0061	S		
15	40	65	90					0037	E		
16	41	66	91					0053	C		
17	42	67	92					0024	TAB		
18	43	68	93					0033	P		
19	44	69	94					0027	.		
20	45	70	95					0003	SP		
21	46	71	96					0033	P		
22	47	72	97					0061	S		
23	48	73	98					0017	I		
24	49	1174	99				8009	0057	A		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS		
00	25	50	1175				8009	0024			TAB
01	26	51	76					0008			V.C.
02	27	52	77					0005			B
03	28	53	78					0004	X		L.C.
04	29	54	79					0027			,
05	30	55	80					0003			SP
06	31	56	81					0006			L
07	32	57	82					0005	X		B
08	33	58	83					0003			SP
09	34	59	84					0042			F
10	35	60	85					0024			TAB
11	36	61	86					0021	X		D
12	37	62	87					0008			V.C.
13	38	63	88					0033			P
14	39	64	89					0004			L.C.
15	40	65	90					0019	X		/
16	41	66	91					0021			D
17	42	67	92					0045			T
18	43	68	93					0027			,
19	44	69	94					0003	X		SP
20	45	70	95					0006			L
21	46	71	96					0005			B
22	47	72	97					0003			SP
23	48	73	98					0042	X		F
24	49	74	1199				8009	0024			TAB

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. 9	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO. 26	
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
1200	25	50	75				8009	0021	D		
01	26	51	76					0008	V.C.		
02	27	52	77					0029	M		
03	28	53	78					0004	X L.C.		
04	29	54	79					0019	/		
05	30	55	80					0021	D		
06	31	56	81					0045	T		
07	32	57	82					0027	X		
08	33	58	83					0003	SP		
09	34	59	84					0006	L		
10	35	60	85					0005	B		
11	36	61	86					0003	X SP.		
12	37	62	87					0029	M		
13	38	63	88					0019	/		
14	39	64	89					0061	S		
15	40	65	90					0037	X E		
16	41	66	91					0053	C		
17	42	67	92					0016	C.B.		
18	43	68	93					0010	2		
19	44	69	94					0003	X SP.		
20	45	70	95					0003	SP.		
21	46	71	96					0008	V.C.		
22	47	72	97					0005	B		
23	48	73	98					0004	X L.C.		
1200	49	74	99				8009	0003	SP		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
										10 36	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:	
										SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS		
00	1225	50	75				8009	0053	C		
01	26	51	76					0029	M		
02	27	52	77					0006	L		
03	28	53	78					0024	TAB		
04	29	54	79					0008	U.C.		
05	30	55	80					0033	P		
06	31	56	81					0004	L.C.		
07	32	57	82					0027	,		
08	33	58	83					0003	SP		
09	34	59	84					0006	L		
10	35	60	85					0005	B		
11	36	61	86					0003	SP		
12	37	62	87					0042	F		
13	38	63	88					0003	SP		
14	39	64	89					0003	SP		
15	40	65	90					0061	S		
16	41	66	91					0037	E		
17	42	67	92					0053	C		
18	43	68	93					0024	TAB		
19	44	69	94					0008	U.C.		
20	45	70	95					0029	M		
21	46	71	96					0004	L.C.		
22	47	72	97					0027	,		
23	48	73	98					0003	SP		
24	1249	74	99				8009	0006	L		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
00	25	1250	75				8009	0005			B
01	26	51	76					0003			SP
02	27	52	77					0029			M
03	28	53	78					0024	X		TAB
04	29	54	79					0008			U.C.
05	30	55	80					0049			H
06	31	56	81					0004			L.C.
07	32	57	82					0027	X		,
08	33	58	83					0008			U.C.
09	34	59	84					0003			SP
10	35	60	85					0005			B
11	36	61	86					0004	X		L.C.
12	37	62	87					0045			T
13	38	63	88					0041			U
14	39	64	89					0024			TAB
15	40	65	90					0021	X		D
16	41	66	91					0008			U.C.
17	42	67	92					0049			H
18	43	68	93					0004			L.C.
19	44	69	94					0019	X		/
20	45	70	95					0021			D
21	46	71	96					0045			T
22	47	72	97					0027			,
23	48	73	98					0003	X		SP
24	49	1274	99				8009	0008			U.C.

LGP-3G CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MAKE APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	25	50	1275				8009	0005			B
01	26	51	76					0004			L.C.
02	27	52	77					0045			T
03	28	53	78					0041	X		V
04	29	54	79					0019			/
05	30	55	80					0061			S
06	31	56	81					0037			E
07	32	57	82					0053	X		C
08	33	58	83					0016			C.R.
09	34	59	84					0014			3
10	35	60	85					0003			SP.
11	36	61	86					0003	X		SP.
12	37	62	87					0008			V.C.
13	38	63	88					0017			I
14	39	64	89					0004			L.C.
15	40	65	90					0003	X		SP.
16	41	66	91					0001			Z
17	42	67	92					0027			,
18	43	68	93					0003			SP.
19	44	69	94					0006	X		L
20	45	70	95					0005			B
21	46	71	96					0003			SP.
22	47	72	97					0042			F
23	48	73	98					0003	X		SP.
24	49	74	1299				8009	0061			S

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
1300	25	50	75				8009	0037			E
01	26	51	76					0053			C
02	27	52	77					0024			TAB
03	28	53	78					0008	X		U.C.
04	29	54	79					0042			E
05	30	55	80					0004			L.C.
06	31	56	81					0003			SP
07	32	57	82					0001	X		Z
08	33	58	83					0027			,
09	34	59	84					0003			SP
10	35	60	85					0006			L
11	36	61	86					0005	X		B
12	37	62	87					0003			SP
13	38	63	88					0042			E
14	39	64	89					0024			TAB
15	40	65	90					0008	X		U.C.
16	41	66	91					0017			I
17	42	67	92					0004			L.C.
18	43	68	93					0003			SP
19	44	69	94					0009	X		Y
20	45	70	95					0027			,
21	46	71	96					0003			SP
22	47	72	97					0006			L
23	48	73	98					0005	X		B
1324	49	74	99				8009	0003			SP



LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES: 14 26	
PROGRAM PREPARED BY:			PROGRAM CHECKED BY:			DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
00	13	25	50	75			8009	0042			F
01	26	51	76					0003			SP.
02	27	52	77					0061			S
03	28	53	78					0037	X		E
04	29	54	79					0053			C
05	30	55	80					0024			TAB
06	31	56	81					0008			U.C.
07	32	57	82					0042	X		F
08	33	58	83					0004			L.C.
09	34	59	84					0003			SP.
10	35	60	85					0009			Y
11	36	61	86					0027	X		I
12	37	62	87					0003			SP.
13	38	63	88					0006			L
14	39	64	89					0005			B
15	40	65	90					0003	X		SP.
16	41	66	91					0042			F
17	42	67	92					0024			TAB
18	43	68	93					0008			U.C.
19	44	69	94					0033	X		P
20	45	70	95					0004			L.C.
21	46	71	96					0007			-
22	47	72	97					0017			I
23	48	73	98					0025	X		N
24	13	49	74	99			8009	0021			D

LGP-30 CODING SHEET (Dictator Format)																		
PREPARED FOR:										JOB NO.			PROGRAM NO.		PAGE NO. 15		NO. OF PAGES 26	
PROGRAM PREPARED BY:					PROGRAM CHECKED BY:					DATE PREPARED:			DATE RUN:		SUPERSEDED BY PROGRAM NO.			
PROBLEM:																		
LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS									
00	25	1350	75				8009	0037	E									
01	26	51	76				8009	0039	X									
02	27	52	77				8009	0016	C.R.									
03	28	53	78			1	0000	1354	X									
04	29	1354	79	3	0100		0136	0000	8g									
05	30	55	80	3	0000		0102	0000	8gR									
06	31	56	81	3	0000		0530	0000	8gR TAN INIT									
07	32	57	82			13	0000	0408	X 8gR INIT									
08	33	58	83	4	0122		0000	0400	A									
09	34	59	84	3	0000		0000	0420	B									
10	35	60	85	3	0000		0026	0426										
11	36	61	86	3	0400		0024	0000	X									
12	37	62	87	1	0000		0426	0000										
13	38	63	88	1	0000		0022	0426	8gR INIT									
14	39	64	89			1	0000	1366										
15	40	65	90			1	0000	1366	X									
16	41	1366	91	4	0532		0000	0402	E INIT									
17	42	17	92	3	0000		0108	0404	8gR INIT									
18	43	18	93	3	0000		0136	0406	8gR INIT									
19	44	69	94	3	0420		0032	0430	X									
20	45	70	95	3	0400		0030	0000										
21	46	71	96	1	0000		0430	0000										
22	47	72	97	1	0000		0028	0430	K <sub>AV</sub> INIT									
23	48	73	98			1	0000	1374	X									
24	49	1374	99	3	0000		0426	0428	8gR INIT									

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. 16	NO. OF PAGES 26
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	25	50	1375			13	0000	0000	(2)AV INIT) 1/2		
01	26	51	76	4	0408		0000	0410	Ab INIT		
02	27	52	77	3	0000		0436	0412	MT Ab INIT		
03	28	53	78	4	0000		0136	0414	X MT Ab INIT / g		
04	29	54	79	4	0406		0412	0418	AT		
05	30	55	80	4	0406		0410	0416	ag Pb INIT / Ab INIT		
06	31	56	81	3	0528		0418	0448	Eg AT		
07	32	57	82	6	0002		0012	0552	X Ey = 0, INIT		
08	33	58	83			1	0000	1384			
09	34	59	84				8000	0015	SET LOOP STR. #0 FOR 16		
10	35	60	35				8008	0016	COND. STOP #16		
11	36	61	86	4	[0144]		0418	0500	X t		
12	37	62	87	3	0402		[0176]	0502	P		
13	38	63	88	3	0404		[0176]	0504	B		
14	39	64	89	3	0404		[0208]	0506	P		
15	40	65	90	3	0416		[0240]	0508	X M		
16	41	66	91	3	0414		[0272]	0510	Br		
17	42	67	92	3	0414		[0304]	0512	P		
18	43	68	93	3	0436		[0336]	0514	M		
19	44	69	94	3	0528		[0368]	0516	X H		
20	45	70	95	3	0448		[0650]	0518	H		
21	46	71	96			1	0000	1397			
22	47	72	97			1	0000	1398			
23	48	73	98	3	0540		0512	0550	X Iy = w P		
24	49	74	1399	3	0540		0506	0552	Fy = w P		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
1400	25	50	75	3	0534		0510	0546			I <sub>2</sub>
01	26	51	76	3	0536		0504	0548			F <sub>2</sub>
1432	27	52	77				8008	0004			COND. STOP # 4
03	28	53	78				8009	0016	X		C.R.
04	29	54	79				8009	0006			I
05	30	55	80				8009	0003			SP
06	31	56	81				8009	0003			SP
07	32	57	82			18	0500	0508	X		T.P.B.P.M
08	33	58	83				8009	0016			C.R.
09	34	59	84				8009	0010			2
10	35	60	85				8009	0003			SP
11	36	61	86				8009	0003	X		SP
12	37	62	87			18	0510	0518			B.P.M.H.H
13	38	63	88				8009	0016			C.R.
14	39	64	89				8009	0014			3
15	40	65	90				8009	0003	X		SP
16	41	66	91				8009	0003			SP
1417	42	67	92			1	0000	1418			SWITCH B
18	43	68	93			18	0546	0552			I <sub>2</sub> , F <sub>2</sub> , I <sub>4</sub> , F <sub>4</sub>
19	44	69	94			18	0536	0536	X		b
20	45	70	95			1	0000	1425			
1421	46	71	96			18	0546	0548			I <sub>2</sub> , F <sub>2</sub>
22	47	72	97				8009	0024			TAB
23	48	73	98				8009	0024	X		TAB
1424	49	74	99			18	0536	0536			b

## LGP-30 CODING SHEET (Dictator Format)

PREPARED FOR:			JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES:		
							18 26		
PROGRAM PREPARED BY:		PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	

PROBLEM:

LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS
00	1425	50	75			9	1386	0002	INCREMENT: $t \quad t+1 = 6$
01	26	51	76			8	1387	0002	$P_n$
02	27	52	77			8	1388	0002	$B$
03	28	53	78			8	1389	0002	$P$
04	29	54	79			8	1390	0002	$M$
05	30	55	80			8	1391	0002	$B_r$
06	31	56	81			8	1392	0002	$P$
07	32	57	82			8	1393	0002	$M$
08	33	58	83			8	1394	0002	$H$
09	34	59	84			8	1395	0002	$H$
10	35	60	85			1	0000	1436	
11	1436	61	86			3	0000	1385	$i$ Loop
12	1437	62	87			1	0000	1438	SWITCH C
13	38	63	88	6	0002		0536	0544	$D_{OFF}$
14	39	64	89				8009	0016	C.R.
15	40	65	90			18	0538	0538	$\lambda_n$
16	1441	66	91			18	0544	0544	$D_{OFF}$
17	42	67	92			18	0540	0540	$\omega$
18	43	68	93				8008	0000	HALT 1
19	1444	69	94	4	0544		0510	0544	$\sum_{i=1}^n b_i (B_{r_i} - B_{r_{i-1}}) / B_{r_n}$
20	45	70	95				8009	0016	C.R.
21	46	71	96			1	0000	1441	
22	1447	72	97	2	0510		0000	0546	$I_2$
23	48	73	98	3	0536		0504	0548	$F_2$
24	1449	74	99	6	0002		0510	0488	$B_{r_i} \Rightarrow B_{r_{i-1}}$

LGP-30 CODING SHEET (Dictator Format)														
PREPARED FOR:							JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES			
PROGRAM PREPARED BY:							PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:														
LOCATION (MAKE APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS					
00	25	1450	75			1	0000	1402						
01	26	1451	76			4	1467	1403	INITIALIZE S ADDR.					
02	27	52	77				8001	0003	SET LOOP CTR. #1 FOR 4					
03	28	53	78	4	0502		0482	0496	X	$P_0/P_m$				
04	29	54	79	3	0000		0000	0520	$(P_0/P_m)^2$					
05	30	55	80	3	0000		0496	0522	$(P_0/P_m)^3$					
06	31	56	81	2	0018		0496	0000	$40 - (P_0/P_m)$					
07	32	57	82			2	1458	1460	X					
08	33	58	83			5	1461	0898	TAKE SET I					
09	34	59	84			1	0000	1461						
10	35	60	85			5	1461	0930	TAKE SET II					
11	35	61	86	6	0008		[0898]	0460	X	$\alpha_j, \beta_{ij} \Rightarrow W.S.$				
12	37	62	87	3	0522		0466	0490						
13	38	63	88	3	0520		0464	0000						
14	39	64	89	1	0000		0490	0490						
15	40	65	90	3	0496		0462	0000	X					
16	41	66	91	1	0000		0490	0000						
17	42	67	92	1	0000		0460	[0468]	$\begin{Bmatrix} a \\ b_i \\ b_j \end{Bmatrix} \Rightarrow [ ]$					
18	43	68	93			8	1461	0008						
19	44	69	94			7	1467	0002	X					
20	45	70	95			3	0001	1461	Loop to 1461 (D)					
21	46	71	96	3	0480		0474	0490						
22	47	72	97	3	0478		0472	0000						
23	48	73	98	1	0000		0490	0490	X					
24	49	1474	99	3	0476		0470	0000						

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
								20		26	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:	
										SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
00	25	50	1475	1	0000		0490	0000			
01	26	51	76	1	0000		0468	0490	$\lambda_m = y_m / \mu_m$		
02	27	52	77			1	0000	1574			
03	28	53	1478	3	0490		0458	0490	X $y_m$		
04	29	54	79	2	0094		0000	0000	$\rho - y_m$		
05	30	55	80			2	1481	1485	FOR $\rho \geq y_m \Rightarrow 1481$		
06	31	56	1481	4	0092		0490	0000	$I / y_m$		
07	32	57	82	3	0000		0000	0000	X $I^2 / y_m^2$		
08	33	58	83	2	0130		0000	0498	$\mu_m$ FOR $\rho \geq y_m$		
09	34	59	84			1	0000	1488			
10	35	60	1485	4	0452		0490	0000			
11	36	61	PC	4	0000		0490	0000	X $(\frac{1}{\mu} \rho^2 - I^2) / y_m^2$		
12	37	62	87	1	0000		0486	0498	$\mu_m$ FOR $\rho < y_m$		
13	38	63	1488	3	0000		0454	0000	$(\mu_m)(1 - \cos \alpha_m)$		
14	39	64	89	3	0000		0494	0000	$[M_{21}(\mu_m)(1 - \cos \alpha_m)]$		
15	40	65	90	3	0000		0560	0000	X $\{ \mu / \pi [ ] \}$		
16	41	66	91	4	0000		0036	0536	$\{ \} / F_2 = b$		
17	42	67	92	2	0510		0488	0000	$[(B_T)_i - (B_T)_{i-1}]$		
18	43	68	93	3	0000		0536	0000	$b [ ]$		
19	44	69	94	1	0000		0544	0544	X $b$ SEE P.S.		
20	45	70	95			1	0000	1447			
21	46	71	1496				1000	1500			
22	47	72	97								
23	48	73	98						X		
24	49	74	99								

LGP-30 CODING SHEET (Dictator Format)													
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO.		NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:													
LOCATION (MARK APPROX. IN LINES)				OPER ACTION	A	OPER ACTION	B	C	REMARKS				
1000	25	50	75			4	1552	1557	CLOSED, SYMM. BRAKE START 2. $A \Rightarrow A_1$				
01	26	51	76			4	1417	1421	$B \Rightarrow B_1$				
02	27	52	77			4	1397	1400	$E \Rightarrow E_3$				
03	28	53	78	6	0002		0012	0540	<input checked="" type="checkbox"/> $W = 0$				
04	29	54	79			1	0000	1512					
1505	30	55	80			5	1585	0052	FREE PERIPHERY BRAKE START 4. INIT. MOVE TO WS. INSTR.				
06	31	56	81			1	0000	1507					
07	32	57	82			4	1552	1613	<input checked="" type="checkbox"/> $A \Rightarrow A_2$				
08	33	58	83			1	0000	1510					
1509	34	59	84			4	1552	1553	CLOSED, ASYMM. BRAKE START 1. $A \Rightarrow A_1$				
10	35	60	85			4	1417	1418	$B \Rightarrow B_1$				
11	36	61	86			4	1397	1398	<input checked="" type="checkbox"/> $E \Rightarrow E_1$				
1512	37	62	87				8000	[0000]	SET BAFFLE LOOP CTS. TO (N-1)				
13	38	63	88	6	0002		0012	0400	$d = 0$ P.S.				
14	39	64	89	6	0006		0400	0402	$b = 0, c = 0, d = 0$ P.S.				
15	40	65	90	6	0002		0130	0410	<input checked="" type="checkbox"/> $K_2 = 1$				
16	41	66	91	6	0002		0130	0412	$E_{10} = 1$				
17	42	67	92	6	0002		0108	0414	$S_{10} = A$				
18	43	68	93			5	1521	0070	INIT. MOVE $S_1$				
19	44	69	94				8008	0004	<input checked="" type="checkbox"/> COND STOP #4				
1520	45	70	95				8008	0004	COND STOP #4				
1521	46	71	96	6	0010		0070	0420	MOVE $S_0, S_1, S_2, S_3, S_4, S_5, S_6, S_7$ TO WS.				
22	47	72	97	1	0420		0422	0416	$S_{0j} + S_{1j}$				
23	48	73	98	4	0000		0414	0000	<input checked="" type="checkbox"/>				
1524	49	74	99	3	0000		0412	0418	$E_{1j}$				



LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO.	NO. OF PAGES
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	SUPERSEDED BY PROGRAM NO.
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	1525	50	75	3	0000		0424	0000			
01	26	51	76	4	0000		0422	0430	$E_j$		
02	27	52	77	7	0000		0740	0682			
03	28	53	78	2	0004		0002	0010	$E_n - E_i$		
04	29	54	79	2	0008		0006	0000			
05	30	55	80	4	0000		0010	0010	$(m_n - m_i) / (E_n - E_i)$		
06	31	56	81	2	0430		0002	0000			
07	32	57	82	3	0000		0010	0000	$m_j$		
08	33	58	83	1	0000		0006	0434			
09	34	59	84	7	0418		0740	0682			
10	35	60	85	2	0004		0002	0010			
11	36	61	86	2	0008		0006	0000			
12	37	62	87	4	0000		0010	0010			
13	38	63	88	2	0418		0002	0000			
14	39	64	89	3	0000		0010	0000			
15	40	65	90	1	0000		0006	0432	$m_j$		
16	41	66	91	4	0422		0416	0000			
17	42	67	92	3	0000		0410	0436	$A_j$		
18	43	68	93	1	0000		0402	0402	$b.p.s. = \frac{2}{3} A_j$		
19	44	69	94	4	0420		0416	0000			
20	45	70	95	3	0000		0410	0410	$K_{j-1}$		
21	46	71	96	3	0436		0432	0000	$A_j m_j$		
22	47	72	97	1	0000		0406	0406	$d.p.s.$		
23	48	73	98			15	0426	0000	$\cos \alpha_j$		
24	1549	74	99	3	0000		0436	0000			

LGP-30 CODING SHEET (Dictator Format)															
PREPARED FOR:								JOB NO.		PROGRAM NO.		PAGE NO. 23		NO. OF PAGES 26	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.			
PROBLEM:															
LOCATION (MARK APPROX. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS						
00	25	1550	75	3	0000		0434	0000	$\Delta_j m_j \cos \alpha_j$						
01	26	51	76	1	0000		0400	0400	G p.s.						
02	27	1562	77			1	0000	1553							
03	28	53	78			15	0428	0000	X						
04	29	54	79	3	0000		0436	0000							
05	30	55	80	3	0000		0434	0000	$\Delta_j m_j \cos \beta_j$						
06	31	56	81	1	0000		0404	0404	C p.s.						
07	32	1567	82			8	1521	0010	X INCR. MAKE S'S INSTR.						
08	33	58	83	6	0004		0418	0412	$E_j \Rightarrow E_{j-1}; S_{aj} \Rightarrow S_{aj-1}$						
09	34	59	84			1	0000	1560							
10	35	1560	85			3	0000	1520	#0 Loop TO 1520						
11	36	61	86	2	0130		0402	0000	X $1 - \frac{1}{2} \Delta_j$						
12	37	62	87	3	0000		0432	0000	$m_{jj} (1 - \frac{1}{2} \Delta_j)$						
13	38	63	88	1	0000		0400	0000							
14	39	64	89	4	0000		0128	0538	$\lambda_a \Rightarrow 0.538$						
15	40	65	90	2	0406		0400	0000	X						
16	41	66	91	1	0000		0124	0542	$\lambda$						
17	42	67	92	3	0000		0208	0000	$\lambda \mu$						
18	43	68	93	4	0000		0176	0536	$\lambda \mu / \bar{E} = b$						
19	44	69	94	2	0130		0000	0534	X $1 - b$						
20	45	70	95	4	0404		0126	0540	$\omega$						
21	46	71	96				8008	0032	COND. STOP. #32						
22	47	72	97			4	1437	1438	$C \Rightarrow C_i$						
23	48	73	98			1	0000	1020	X						
24	49	1574	99	3	0000		0000	0000	$\lambda \bar{E}$						

LGP-36 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. 24	NO. OF PAGES 26
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:	
PROBLEM:											
LOCATION (MAPS APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	25	50	1575	3	0000		0484	0000	$\frac{2}{\pi} \lambda_m$		
01	26	51	76	1	0000		0130	0492	$1 + \frac{2}{\pi} \lambda_m \equiv \epsilon_{21}$		
02	27	52	77	7	0000		0740	0682	T.L.U. : $m(\epsilon_{21})$		
03	28	53	78	2	0008		0006	0010	$m_n - m$		
04	29	54	79	2	0004		0002	0000	$\epsilon_n - \epsilon_1$		
05	30	55	80	4	0010		0000	0010			
06	31	56	81	2	0492		0002	0000	$\epsilon_n - \epsilon_1$		
07	32	57	82	3	0000		0010	0000			
08	33	58	83	1	0000		0006	0494	$m_{21}$		
09	34	59	84			1	0000	1478			
10	35	60	1585			4	1397	1587	$E \Rightarrow E_1$		
11	36	61	86			1	0000	1020			
12	37	62	1587			4	1603	0468	INIT. B' ADDR.		
13	38	63	88				8001	0002	SET LOOP CTR. #1 FOR 3		
14	39	64	89	4	0502		0482	0496	$(P_n / P_r)$		
15	40	65	90	3	0000		0000	0520	$(P_n / P_r)^2$		
16	41	66	91	3	0000		0496	0522	$(P_n / P_r)^3$		
17	42	67	92	2	0034		0496	0000	$156 - (P_n / P_r)$		
18	43	68	93			2	1594	1596			
19	44	69	1594			5	1597	0798	TAKE SET 1		
20	45	70	95			1	0000	1597			
21	46	71	96			5	1597	0822	TAKE SET II		
22	47	72	1597	6	0008		[0798]	0460	$\alpha_j, \beta_{ij} \Rightarrow W.S.$		
23	48	73	98	3	0522		0466	0490			
24	49	74	1599	3	0520		0464	0000			

LSP-3C CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.:		PROGRAM NO.:		PAGE NO.	NO. OF PAGES
										25	26
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:	
PROBLEM:											
LOCATION (MARK APPROX. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
1600	25	50	75	1	0000		0490	0490			
01	26	51	76	3	0496		0462	0000			
02	27	52	77	1	0000		0490	0000			
1603	28	53	78	1	0000		0460	[0468]	<input checked="" type="checkbox"/> $a', b', b'$		
04	29	54	79			8	1597	0000	INCR. $T'$ ADDR.		
05	30	55	80			7	1603	0002	INCR. $E'$ ADDR.		
06	31	56	81			3	0001	1597	#1 Loop TO 1597		
07	32	57	82	3	0478		0472	0490	<input checked="" type="checkbox"/> $b, \sigma_m$		
08	33	58	83	3	0476		0470	0000	$b, \sigma_m$		
09	34	59	84	1	0000		0490	0000			
10	35	60	85	1	0000		0468	0490	$\lambda_m$		
11	36	61	86			1	0000	1575	<input checked="" type="checkbox"/>		
12	37	62	87				8008	0032	COND. STOP # 22		
1613	38	63	88	6	0006		[0052]	0440	$z_{ij} \Rightarrow W.S.$		
14	39	64	89			15	0440	0446	$\cos z_{ij}$		
15	40	65	90			15	0442	0000	<input checked="" type="checkbox"/> $\cos z_{ij}$		
16	41	66	91	2	0446		0000	0446	$C = z_{ij} - \cos z_{ij}$		
17	42	67	92	2	0020		0440	0448	$\pi/2 - z_{ij}$		
18	43	68	93			14	0444	0000	$\sin z_{ij}$		
19	44	69	94	3	0000		0448	0000	<input checked="" type="checkbox"/> $(\pi/2 - z_{ij}) \sin z_{ij}$		
20	45	70	95	1	0000		0446	0000	$[\cos z_{ij} - \cos z_{ij} + (\ ) \sin z_{ij}]$		
21	46	71	96	3	0000		0436	0000	$A_j, I, 1$		
22	47	72	97	3	0000		0434	0448	$m_j A_j, I, 2$		
23	48	73	98			1	0000	1624	<input checked="" type="checkbox"/>		
1324	49	74	99	4	0000		0016	0000	$\omega$ P.S.		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES 26 26	
PROGRAM PREPARED BY:			PROGRAM CHECKED BY:			DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	1625	50	75	1	0000		0404	0404			
01	26	51	76			8	1613	0006	INCR. ADDR. OF MOVE INSTR.		
02	27	52	77			1	0000	1557			
03	1628	53	78	4	0090		0016	0484	X $2^1/\pi$		
04	29	54	79	2	0130		0000	0486	1- $2^1/\pi$		
05	30	55	80	3	0452		0484	0000	$2^1/\pi Q^2$		
06	31	56	81	2	0000		0450	0452	$2^1/\pi Q^2 - I^2$		
07	1632	57	82			1	0000	1010	X		
08	33	58	83								
09	34	59	84								
10	35	60	85								
11	36	61	86						X		
12	37	62	87								
13	38	63	88								
14	39	64	89								
15	40	65	90						X		
16	41	66	91								
17	42	67	92								
18	43	68	93								
19	44	69	94						X		
20	45	70	95								
21	46	71	96								
22	47	72	97								
23	48	73	98						X		
24	49	74	99								

# SAMPLE BRAKE ANALYSES

I. An example of a type 1 brake which has been analysed by use of DIPARDIP is the single-baffle, closed, asymmetric brake pictured in figure 0.1 of the INTRODUCTION. When used with the standard 105mm howitzer at zone 7, the weapon-break system produces the following data.

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0100	1.2593	$\gamma$
0102	70.036	R
0104	1350	$e_c$
0106	1231	$e_{ig}$
0108	13.717	A
0110	10.896	$A_{cnct}$
0112	1431.17	$\sqrt{T}$
0114	2.83	$M_c$
0116	.042857	$M_{ig}$
0118	33	$M_p$
0120	1492	$M_r$
0122	1550	$v_o$
-----		
0070	15.6228	$S_{01}$
0072	40	$S_{11}$
0074	53.19	$S_{21}$
0076	1.5707 (90°)	$\alpha_1$
0078	0.6109 (35°)	$\beta_1$

The printed results take the following form:

The computer print out for the following sample brake analyses is in the "+50" system of notation. The "+50" system is analogous to the powers-of-ten notation used in scientific work, i.e.,

$$.0004172 = 4.172 \times 10^{-4}$$

$$8190000.0 = 8.19 \times 10^6$$

$$-27.05 = -2.705 \times 10^1$$

In the "+50" system these numbers would be written:

$$4.172 \times 10^{-4} = 41720000'+46'$$

$$8.19 \times 10^6 = 81900000'+56'$$

$$-27.05 = 27050000'-51'$$

Notice that to obtain the correct "characteristic" or exponent of the "+50" system, the usual exponent of 10 is algebraically added to the "base" 50. The sign of the number always preceeds the "characteristic." The "mantissa" is always eight digits long. If there aren't enough significant digits to fill eight spaces, fill out with zeros as was done in the above examples.

## ENERGIES

tot  
prc.j  
gas, kin  
rec mass  
engrv  
gas, therm

## Btu

38732570+53  
15848781+53  
44955162+51  
38098992+51  
22665848+52  
19786662+53

av T

19826223+53

av p

33447631+53

## SINGLE BAFFLE, ASYMMETRICAL BRAKE

U-FU

1 t, sec  
2 H cm  
3 I z, lb f sec

p, psia  
P, lb f sec  
F z, lb f

B, lb f  
M, lb m  
I y, lb f sec

dP/dt, lb f  
H, Btu  
F y, lb f

dM/dt, lb m/sec  
dH/dt, Btu/sec  
P-index

1 39982950+46 35474565+53  
2 20385754+51 13879082+51  
3 72108659+50 31448244+54  
1 79965901+46 32359190+53  
2 38972881+51 26533619+51  
3 13785520+51 28686461+54  
1 11994885+47 29542847+53  
2 55934943+51 38081775+51  
3 19785354+51 26189769+54  
1 15993180+47 26994444+53  
2 7142718+51 48629245+51  
3 25265284+51 23930607+54  
1 19991474+47 24686356+53  
2 85588844+51 58270820+51  
3 30274556+51 21884484+54  
1 27988065+47 20695579+53  
2 11040747+52 75167907+51  
3 39053423+51 18346655+54  
1 39982952+47 15979149+53  
2 14039437+52 95583666+51  
3 49660414+51 14165535+54  
1 51977835+47 12420617+53  
2 16362256+52 11139794+52  
3 57876707+51 11010892+54  
1 63972720+47 97162547+52  
2 18173357+52 12372832+52  
3 64282947+51 86134713+53  
1 79965901+47 70692786+52  
2 19997603+52 13614820+52  
3 70735687+51 62669238+53  
1 99957376+47 48177814+52  
2 21605748+52 14709683+52  
3 76424030+51 42709688+53  
1 12394714+48 30997101+52  
2 22885603+52 15581036+52  
3 80951143+51 27478967+53  
1 14793691+48 20328933+52  
2 23716519+52 16146742+52  
3 83890268+51 18021623+53  
1 17992327+48 11901330+52  
2 24405473+52 16615798+52  
3 86327241+51 10550543+53  
1 24389600+48 44238485+51  
2 25063028+52 17063477+52  
3 88653150+51 39217469+52  
1 29987213+48 20072478+51  
2 25296588+52 17222490+52  
3 87473300+51 17794276+52  
38284936+49 64627921+49

48660460+54 20408599+49  
11609319+51 44387102+54  
39194354+9 22194354+51  
40523923+54 56499941+49  
31853945+51 26189769+54  
37028279+54 72541264+49  
40676498+51 33862274+54  
87173520+49 48741304+51  
28388126+54 11332048+50  
62875071+51 21918599+54  
14561929+50 79952070+51  
17037361+54 17130521+50  
93180103+51 13327786+54  
19185249+50 10349399+52  
96969294+53 66018889+53  
21315186+50 11388274+52  
66085506+53 23261206+50  
12304085+52 42518724+53  
24876549+50 13032939+52  
27885197+53 25973036+50  
13506131+52 16325055+53  
26927360+50 13898477+52  
60681930+52 27907714+50  
14272944+52 27533417+52  
28290306+50 19684626+53  
14405952+52 83646164+49

33129140+54 17535141+52  
27711255+54 30219742+54  
33371841+52 25277654+54  
27589603+54 47688445+52  
23077644+54 25209690+54  
60642997+52 21086938+54  
23054202+54 72375939+52  
19283955+54 19327278+54  
92662668+52 16166526+54  
14922677+54 11663817+53  
12482247+54 11599421+54  
13472762+53 97024708+53  
90738584+53 14847499+53  
75899343+53 66018889+53  
16193063+53 55222268+53  
44992509+53 17337590+53  
37634508+53 28947709+53  
18210955+53 24213647+53  
18984872+53 18753261+53  
15801117+53 11114466+53  
19181670+53 92968247+52  
41313631+52 19561780+53  
34557268+52 18745374+52  
19684626+53 15679786+52

48951311+52 41653713+55  
64627921+49 45076975+52  
37637816+53 64627921+49  
41541370+52 34041430+53  
64627921+49 38312137+52  
30817422+53 64627921+49  
75360235+52 27924312+53  
64627921+49 30187012+52  
22988340+53 64627921+49  
23936487+52 17283463+53  
64627921+49 19094759+52  
13090436+53 64627921+49  
15319668+52 99846388+54  
64627921+49 11517174+52  
70305320+54 64627921+49  
81651219+51 46059104+54  
64627921+49 54973706+51  
28318557+54 64627921+49  
37653934+51 17782907+54  
64627921+49 23293249+51  
98524659+53 64627921+49  
7870265+50 33075056+53  
64627921+49 47186572+50  
13834632+53 64627921+49



II. A hypothetical triple-baffle, closed, symmetric brake, which is used with the 105mm howitzer is analysed in this example. Figure 0.2 of the INTRODUCTION illustrates this type. Since the thermodynamic data for this example is identical to that of example I, the contents of locations 0100-0122 are not written here, only the brake data being given.

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0070	16	$S_{01}$
0072	50	$S_{11}$
0074	100	$S_{21}$
0076	2.3562 (135°)	$\alpha_1$
0078	1.5707 (90°)	$\beta_1$
0080	20	$S_{02}$
0082	50	$S_{12}$
0084	100	$S_{22}$
0086	2.3562	$\alpha_2$
0088	1.5707	$\beta_2$
0090	25	$S_{03}$
0092	50	$S_{13}$
0094	100	$S_{23}$
0096	2.3562	$\alpha_3$
0098	1.5707	$\beta_3$

The computer print out for example II follows.

ENERGIES  
tot 38732570+53  
proj 15848781+53  
gas, kin 44955162+51  
rec mass 35098992+51  
engrv 22665848+52  
gas, therm 19786662+53

av T 19826223+53  
av F 33447631+53

105 MM HOWITZER AT ZONE 7  
WITH A TRIPLE-BAFFLE, CLOSED,  
SYMMETRIC BRAKE

1	t, sec	P, psia	B, lb f	dP/dt, lb f	dM/dt, lb m/sec
2	B cml	P, lb f sec	M, lb m	H, Btu	dH/dt, Btu/sec
3	I z, lb f sec	F z, lb f	I y, lb f sec	F y, lb f	P-index
1	39962595+46	35213178+53	48713426+54	33165201+54	48976245+52
2	20397554+51	13887115+51	20408599+49	17535141+52	41674931+55
3	12553620-51	78693976+54			16154474+50
1	79925189+46	32394413+53	44435416+54	30252636+54	45099936+52
2	38995440+51	26548977+51	39194355+49	33371841+52	37656988+55
3	23999640-51	71783076+54			16154474+50
1	11988778+47	29575004+53	40568032+54	27619633+54	41562530+52
2	55967319+51	38103817+51	56499941+49	47688445+52	34058769+55
3	34444937-51	65535522+54			16154474+50
1	15985037+47	27023828+53	37068584+54	25237131+54	38331653+52
2	71468532+51	48657391+51	72454126+49	60642997+52	30833120+55
3	43985117-51	59882348+54			16154474+50
1	19981296+47	24713227+53	33899134+54	23079296+54	35378268+52
2	85638383+51	58304548+51	87173520+49	72375939+52	27938537+55
3	52705915-51	54762266+54			16154474+50
1	27973815+47	20718106+53	28419026+54	19348315+54	30202388+52
2	11047138+52	75211414+51	11332048+50	92662668+52	23000650+55
3	67989318-51	45909440+54			16154474+50
1	39962595+47	15996542+53	21942457+54	14938920+54	23948680+52
2	14047563+52	95638990+51	14561929+50	11663817+53	17292269+55
3	86455360-51	35446885+54			16154474+50
1	51951372+47	12434137+53	17055906+54	11612046+54	19104486+52
2	16371726+52	11146241+52	17130521+50	13472762+53	13097165+55
3	10075936-52	27552919+54			16154474+50
1	63940151+47	97268307+52	13342293+54	90837350+53	15327471+52
2	18183075+52	12379993+52	19185249+50	14847499+53	99897247+54
3	11191218-52	21553773+54			16154474+50
1	79925188+47	70769733+52	97074843+53	66090750+53	11523041+52
2	20009178+52	13622700+52	21315186+50	16193063+53	70341132+54
3	12314595-52	15681930+54			16154474+50
1	99906486+47	48230254+52	66157440+53	45041482+53	81692811+51
2	21618253+52	14718197+52	23261206+50	17337590+53	46032565+54
3	13304896-52	10687386+54			16154474+50
1	12388404+48	31030841+52	42565004+53	28979218+53	55001708+51
2	22898849+52	15590054+52	24876549+50	18210955+53	28332982+54
3	14093036-52	68761526+53			16154474+50
1	14786160+48	20351060+52	27915549+53	19005537+53	37673115+51
2	23730246+52	16156089+52	25973036+50	18753261+53	17791965+54
3	14604717-52	45096100+53			16154474+50
1	17983167+48	11914284+52	16342824+53	11126564+53	23305114+51
2	24419599+52	16625415+52	26527360+50	19181670+53	98574846+53
3	15020977-52	26400972+53			16154474+50
1	24377182+48	44286638+51	60747981+52	41358600+52	95919099+50
2	25077534+52	17073354+52	27907714+50	19561780+53	33091903+53
3	15433902-52	98135167+52			16154474+50
1	29971945+48	20094327+51	27563388+52	18765778+52	47210609+50
2	25311229+52	17232458+52	28290306+50	19684626+53	13841679+53
3	15577729-52	44527202+52			16154474+50
994	45308-49	16154474+50	00000000+49		

III. The single-baffle open brake, pictured in figure 0.3 of the INTRODUCTION, has been analysed using DIPARDIP. When this brake is used with the XM103 cannon at zone 11, the following system data are used in the analysis.

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0090	1.4388 (82.5°)	$\psi$
0092	2.21	I
0094	7.86	Q
0096	5.85	$z_m$
0098	1.9635 (112.5°)	$\alpha_1$
0100	1.2402	$\gamma$
0102	67	R
0104	1727.5	$e_c$
0106	1231	$e_{ig}$
0108	13.717	A
0110	10.8984	$A_{cnct}$
0112	1710	$\psi_T$
0114	4.46	$M_C$
0116	0.042837	$M_{ig}$
0118	28.5	$M_p$
0120	1430	$M_r$
0122	2200	$v_o$

The results of the analysis of this example follow.

ENERGIES  
tot 77574071+53  
proj 27574571+53  
gas, kin 14217041+52  
rec mass 63781100+51  
engrv 39435274+52  
gas, therm 43996456+53

XM103 CANNON AT ZONE 11  
WITH SINGLE-BAFFLE,  
GERMAN, OPEN BRAKE

av T 27235043+53  
av p 57660201+53

1 t, sec	p, psia	B, lb f	dP/dt, lb f	dM/dt, lb m/sec
2 B cml	P, lb f sec	M, lb m	H, Btu	dH/dt, Btu/sec
3 I z, lb f sec	F z, lb f	I y, lb f sec	F y, lb f	P-index
1 38612499+46	65408216+53	89720448+54	61083708+54	79448446+52
2 36299034+51	24713203+51	31988020+49	38990108+52	95906011+55
3 12910970-50	92911659+54			10355683+50
1 77224936+46	59664069+53	81841205+54	55719341+54	73160362+52
2 69395419+51	47245970+51	61432428+49	74203662+52	86659571+55
3 28123245-50	85602916+54			10459635+50
1 11583749+47	54471279+53	74718253+54	50869874+54	67422042+52
2 99598199+51	67808710+51	88556846+49	10603722+53	78379033+55
3 115265971-50	78959169+54			10567587+50
1 15444999+47	49772518+53	68272964+54	46481779+54	62180967+52
2 12718381+52	86589616+51	11356310+50	13484220+53	70955885+55
3 67268782-50	73718547+54			10797619+50
1 19306249+47	45516853+53	62435467+54	42507477+54	57390035+52
2 15240016+52	10375748+52	13663398+50	16093087+53	64294616+55
3 90214535-50	68116815+54			10909955+50
1 27028748+47	38158633+53	52342195+54	35635751+54	48993811+52
2 19659241+52	13384456+52	17761619+50	20603925+53	52931116+55
3 13876987-51	58093190+54			11098729+50
1 38612499+47	29462451+53	40413644+54	27514522+54	38849148+52
2 24998733+52	17019702+52	22824068+50	25934978+53	39794489+55
3 21440872-51	46138612+54			11416592+50
1 50196246+47	22901209+53	31413589+54	21387082+54	30990977+52
2 29134762+52	19835604+52	26850028+50	29957240+53	30140346+55
3 29187960-51	37297587+54			11873073+50
1 61779996+47	17914888+53	24573853+54	16730434+54	24863968+52
2 32359622+52	22031162+52	30070565+50	33014025+53	22989232+55
3 37287181-51	30745566+54			12511495+50
1 77224936+47	13034578+53	17879256+54	12172602+54	18692485+52
2 35607389+52	24242656+52	33408984+50	36005942+53	16187519+55
3 45242431-51	22258020+54			12449074+50
1 96531245+47	88830542+52	12184885+54	82957458+53	13252071+52
2 38471364+52	26192176+52	36459137+50	38550845+53	10604924+55
3 50311224-51	14341798+54			11770154+50
1 11969874+48	57152642+52	78396280+53	53373959+53	89222852+51
2 40750284+52	27743715+52	38990992+50	40492808+53	65202346+54
3 52321012-51	85310077+53			10881904+50
1 14286624+48	37482607+52	51414893+53	35004422+53	61112697+51
2 42229820+52	28751017+52	40709602+50	41698648+53	40944433+54
3 52350629-51	51517815+53			10020018+50
1 17375624+48	21943744+52	30100234+53	20492919+53	37805166+51
2 43456576+52	29586221+52	42203391+50	112651233+53	22684909+54
3 51162351-51	27184625+53			90313670+49
1 23553624+48	81567184+51	11188570+53	76174323+52	15359836+51
2 44627423+52	30383361+52	43741977+50	43496423+53	76153995+53
3 48521706-51	86651805+52			77446717+49
1 28959373+48	37009756+51	50766283+52	34562833+52	76584261+50
2 45043303+52	30666501+52	44341646+50	43769575+53	31853689+53
3 47357602-51	36556079+52			72008581+49
11051379+50	00000300+49			

IV. As a final example of the use of DIPARDIP, a double-baffle, closed, free-periphery brake was chosen. This is pictured in figure 0.4 of the INTRODUCTION. The brake was designed to be used with an improved 155mm howitzer for which the system data are given below.

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0052	0.78530	$v_{11}^h$
0054	1.44835	$v_{21}^h$
0056	0.314136	$v_{31}^h$
0058	0.78530	$v_{12}^h$
0060	1.44835	$v_{22}^h$
0062	0.314136	$v_{32}^h$
- - - - -		
0070	31.371	$S_{01}$
0072	139.0	$S_{11}$
0074	16.36	$S_{21}$
0076	2.3562 (135°)	$\alpha_1$
0078	1.5707 (not used)	$\beta_1$
0080	32.170	$S_{02}$
0082	139.0	$S_{12}$
0084	222.5	$S_{22}$
0086	2.3562	$\alpha_2$
- - - - -		
0100	1.2402	$\gamma$
0102	67	$R$
0104	1727.5	$e_c$
0106	1500	$e_{ig}$
0108	29.823	$A$

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0110	19.30	$A_{cnct}$
0112	6707.1	$\sqrt{\tau}$
0114	24.08	$M_c$
0116	2.714 $10^{-3}$	$M_{ig}$
0118	95	$M_p$
0120	4900	$M_r$
0122	2700	$v_o$

The print out of this analysis follows.

## ENERGIES

tot 41602270+54  
 proj 13844258+54  
 gas, kin 11449128+53  
 rec mass 33909495+52  
 engrv 16126798+53  
 gas, therm 24661325+54

av T 28543649+53  
 av p 82401704+53

155 MM HOWITZER WITH TWO BAFFLE,  
 FREE PERIPHERY BRAKE

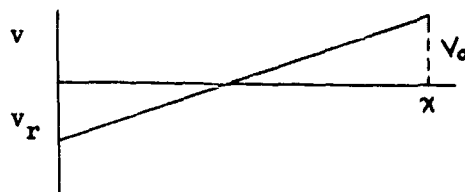
1	t, sec	p, psia	B, lb f	dP/dt, lb f	dm/dt, lb m/sec
2	B cml	P, lb f sec	M, lb m	H, Btu	dH/dt, Btu/sec
3	I z, lb f sec	F z, lb f	I y, lb f sec	F y, lb f	P-index
1	62822650+46	10118946+54	30177733+55	20545682+55	26116461+53
2	19864543+52	13524230+52	17108212+50	21855118+53	33041229+56
3	11966464-52	48356926+55	51310358+51	77949453+54	16024042+50
1	12564529+47	92303010+53	27527526+55	18741362+55	24049429+53
2	37976446+52	25835222+52	32856020+50	41593363+53	29855675+56
3	22877171-52	44110225+55	98093627+51	71103937+54	16024042+50
1	18846794+47	84269529+53	25131701+55	17110230+55	22163116+53
2	54504832+52	37108124+52	47363021+50	59437023+53	27002891+56
3	32833939-52	40271143+55	14078665+52	64915491+54	16024042+50
1	25129060+47	77000334+53	22963809+55	15634281+55	20440259+53
2	69600981+52	47385922+52	60737100+50	75583073+53	24445492+56
3	41927923-52	36797305+55	17978019+52	59315003+54	16024042+50
1	31411324+47	70416626+53	21000350+55	14297513+55	18865374+53
2	83400559+52	56780986+52	73076206+50	90206554+53	22150573+56
3	50240845-52	33651049+55	21542467+52	54244162+54	16024042+50
1	43975853+47	59033128+53	17605449+55	11986188+55	16105349+53
2	10758464+53	73246060+52	94994801+50	11549114+54	18235657+56
3	64809440-52	28211046+55	27789245+52	45475092+54	16024042+50
1	62822651+47	45579743+53	13593246+55	92545895+54	12770574+53
2	13680485+53	93139840+52	12207038+51	14537328+54	13709869+56
3	82411819-52	21781876+55	35336862+52	35111522+54	16024042+50
1	81669443+47	35429205+53	10566051+55	71936072+54	10187419+53
2	15943916+53	10854978+53	14360250+51	16791926+54	10383854+56
3	96046818-52	16931086+55	41183330+52	27292242+54	16024042+50
1	10051623+48	27715141+53	82654868+54	56273300+54	81733362+52
2	17708711+53	12056491+53	16082696+51	18505344+54	79201760+55
3	10667802-53	13244650+55	45741818+52	21349853+54	16024042+50
1	12564529+48	20164771+53	60137398+54	40942901+54	61446332+52
2	19486316+53	13266724+53	17868189+51	20182404+54	55768717+55
3	11730639-53	96364420+54	50333394+52	15533564+54	16024042+50
1	15705662+48	13742485+53	40984214+54	27902981+54	43562488+52
2	21053345+53	14333595+53	19497508+51	21608898+54	36535744+55
3	12682623-53	65673279+54	54381054+52	10586273+54	16024042+50
1	19475021+48	63417717+52	26368816+54	17952435+54	29329524+52
2	22300477+53	15182670+53	20853624+51	22697426+54	22463302+55
3	13433901-53	42253501+55	57602410+52	68110775+53	16024042+50
1	23244380+48	57987287+52	17293548+54	11773838+54	20089095+52
2	23110149+53	15733912+53	21727792+51	23373335+54	14106044+55
3	13921650-53	27711255+54	59693801+52	44669447+53	16024042+50
1	28279192+48	33747962+52	10124501+54	68928529+53	12427394+52
2	23701408+53	16110775+53	22572788+51	23307237+54	78153316+54
3	14326068-53	16223222+54	61427379+52	26151193+53	16024042+50
1	30321815+48	12613011+52	37633382+53	25622145+53	51143621+51
2	24422231+53	16627200+53	25374673+51	24331042+54	26236328+54
3	14712054-53	62303974+53	63602923+52	97206717+52	16024042+50
1	41164077+48	57255744+51	17075308+53	11625300+53	25174940+51
2	24641017+53	10712156+53	23715321+51	24534152+54	10741300+54
3	14712054-53	23715321+53	63707173+52	44105735+52	16024042+50
1	12570747-48	10245042+50	37135163+53		

## APPENDIX I

### Momentum and Energy Distribution at Start of Gas Discharge Period

In a frame of reference which is stationary with respect to the ground, the assumed velocity distribution in the gas behind the projectile within a gun tube of uniform cross section and length  $x$  is shown below in figure 1.1

Figure 1.1



$$v = \left( \frac{v_o + v_r}{L} \right) x - v_r$$

$$x = \xi + \frac{V_c}{A}$$

$$L = \xi_o + \frac{V_c}{A}$$

Let  $\frac{x}{L} = \eta$ , then

$$1.1 \quad \frac{v}{v_o} = \left( 1 + \frac{v_r}{v_o} \right) \eta - \frac{v_r}{v_o} .$$

Now, momentum conservation requires that

$$1.2a \quad \frac{M_r v_r}{g} = P_T + \frac{M_p}{g} v_o \quad \text{or}$$

$$b \quad v_r = \frac{P_T + M_p v_o / g}{M_r / g} .$$

However,  $P_T$ , the momentum taken by the charge and igniter gases, is found by averaging the momentum distribution, i.e.,



$$1.3a \quad P_T = \frac{\dot{M}_T}{gL} \int_0^L v \, dx \quad \text{or}$$

$$P_T = \frac{M_T v_o}{g} \int_0^1 \frac{v}{v_o} (\eta) \, d\left(\frac{x}{L}\right)$$

$$b \quad P_T = \frac{M_T v_o}{g} \int_0^1 \left[ \left(1 + \frac{v_r}{v_o}\right) \eta - \frac{v_r}{v_o} \right] d\eta$$

$$P_T = \frac{M_T v_o}{2g} \left(1 - \frac{v_r}{v_o}\right)$$

Substitution of 1.3b into 1.2b gives

$$1.4 \quad \frac{v_r}{v_o} = \frac{\frac{M_T}{2} + M_p}{\frac{M_T}{2} + M_r}$$

Since the projectile leaves the muzzle with velocity  $v_o$ , it carries off an energy given by

$$KEP = \frac{1}{2} M_p v_o^2$$

In engineering units the kinetic energy of the projectile in Btu is

$$1.5 \quad KEP = \frac{M_p v_o^2}{2gJ}$$

Similarly, the kinetic energy of the recoiling parts is

$$1.6 \quad KER = \frac{M_r v_r^2}{2gJ} \quad \text{with } v_r \text{ being given by equation 1.4}$$

The kinetic energy of the gas itself may be found by integration of an elemental mass of gas over the entire internal volume of the gun tube. Thus

$$1.7 \quad KEG = \frac{1}{2} \frac{M_T v_o^2}{g} \int_0^1 \left(\frac{v}{v_o}\right)^2 d\eta$$

Substitution of 1.1 for  $\frac{v}{v_0}$  and integration yields, in Btu

$$1.8 \quad KEG = \frac{1}{2} \frac{M_T v_0^2}{gJ} \left[ \left( \frac{1+v_r}{v_0} \right)^3 + \left( \frac{v_r}{v_0} \right)^2 - \frac{v_r}{v_0} \left( \frac{1+v_r}{v_0} \right) \right].$$

After an assumed initial shear deformation in the ammunition band as the projectile leaves the chamber, during which relatively little energy is expended, work is performed in forcing the projectile thru the tube against frictional forces. The energy thereby expended, called the engraving energy, is computed as follows.

The minimum pressure which may exist between the band and the walls of the tube to effect a seal is the pressure at the base of the projectile,  $p$ . Using .18 as the effective coefficient of friction between the band and walls, the frictional force is given by

$$.18 A_{cnct} p.$$

The work performed by this force in Btu is, then,

$$1.9 \quad KEB = .18 A_{cnct} \int_{\xi_1}^{\xi_0} p d\xi, \text{ where } \xi_1 \text{ is the travel of the projectile during band deformation.}$$

$$\text{However, } KEP = A \int_{\xi_1}^{\xi_0} p d\xi.$$

Hence,

$$1.10 \quad KEB = \frac{.18 A_{cnct}}{A} KEP.$$

The sources of energy for the sinks mentioned above are the energies obtained by the combustion of the igniter and charge. Thus

$$1.11a \quad \mathcal{H}_{ig} = e_{ig} M_{ig}$$

b  $\mathcal{H}_c = e_c M_c$ , where  $e_{ig}$  and  $e_c$  are the heats of explosion for the igniter and charge, respectively. The total energy is, therefore,

$$1.12 \quad \mathcal{H} = \mathcal{H}_{ig} + \mathcal{H}_c.$$

At the start of the gas discharge, the thermal energy remaining in the gas (assumed to be completely combusted) can be found by subtracting all of the above kinetic energies from the total energy. Thus,

$$1.13 \quad E_g = \mathcal{H} - \Sigma KE's$$

This energy can be expressed in terms of the average initial temperature of the gas,  $T_g = T_{av \text{ init}}$ .

$$1.14 \quad E_g = T_g M_T C_v$$

However,  $C_v = \frac{R}{(\gamma - 1) J}$ . Substituting the latter expression into equation 1.14 and solving for  $T_g$  gives

$$1.15 \quad T_g = \frac{E_g (\gamma - 1) J}{R M_T} .$$

At  $t_0$  the gas behaves in a nearly ideal fashion so that

$$1.16 \quad \frac{pV}{12} = RT \quad \text{where}$$

$$1.17 \quad V = \frac{\mathcal{V}_T}{M_T} .$$

From the last three relationships, one can solve for the average initial pressure in the gas as

$$1.18 \quad p_g = \frac{12 E_g (\gamma - 1) J}{\mathcal{V}_T} .$$

Figure 1.2 shows graphically the energy distribution at the start of gas discharge for the standard 105mm howitzer (zone 7). Values for the energy of all sources and sinks (including some for which no equations are given here) have been computed. Some are seen to be negligible and were not considered in subsequent analyses.

PERCENT DISTRIBUTION OF ENERGY  
AT EJECTION OF PROJECTILE  
FROM STANDARD 105MM HOWITZER  
(ZONE 7)

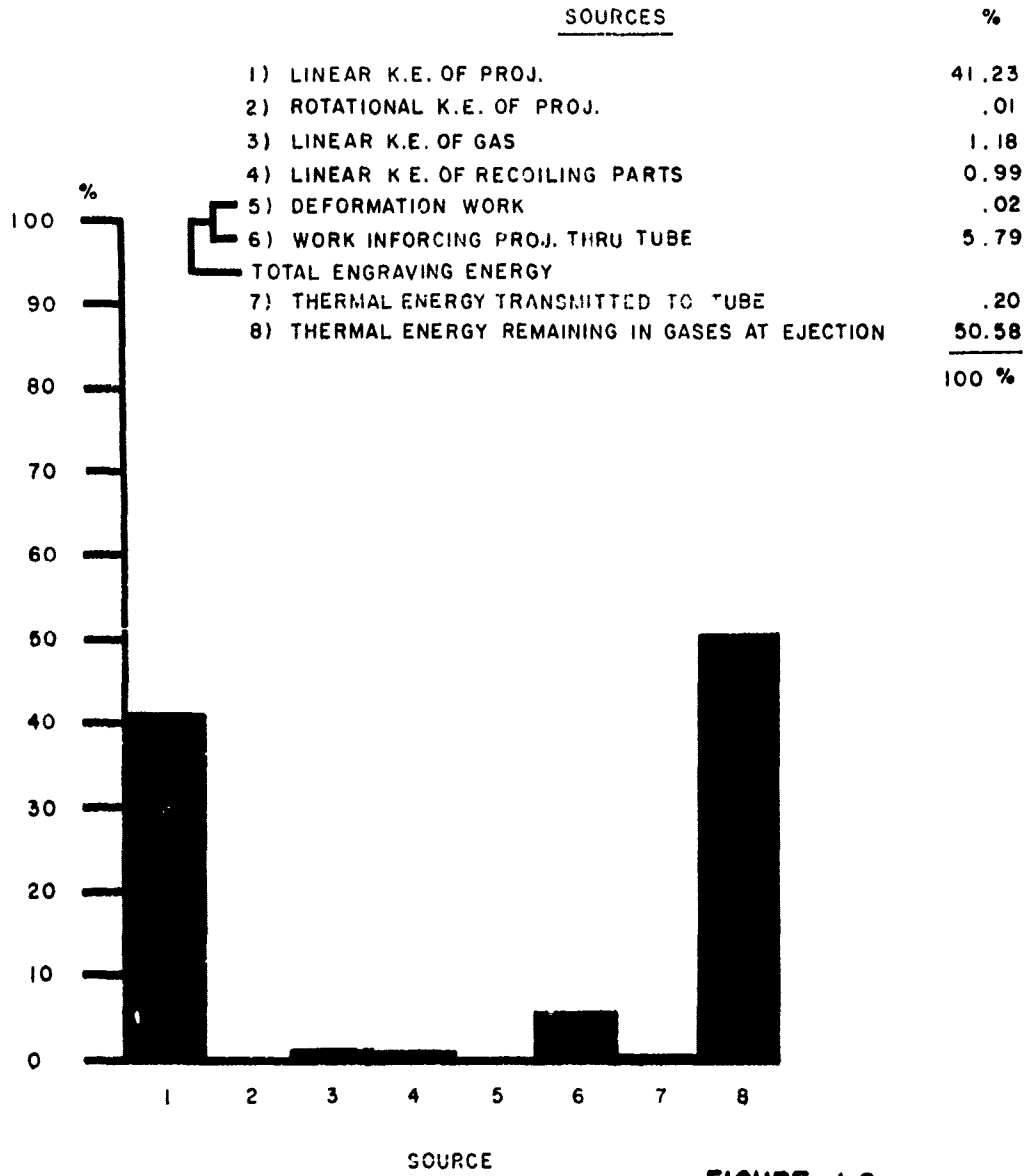


FIGURE 1.2

## APPENDIX II

Derivation of the Relationships:

$$\underline{\phi_{av}(\beta), \eta_{av}(\beta), v_{av}^i(\beta)}$$

Having determined the average pressure, temperature, and specific volume in the gas within the gun tube at  $t_o$ , it is desirable to compute their local values anywhere along the tube length--and, in particular, at the breech--as a function of the average values and the muzzle velocity.

As before, we examine a tube of uniform cross section of length  $L$  and total internal volume  $V$ , and we define a dimension  $x$  such that

$$2.1 \quad x = \xi + \frac{V_c}{A}, \text{ where}$$

$$2.2 \quad L = \xi_o + \frac{V_c}{A}.$$

For convenience, let us also define some dimensionless variables:

$$2.3a \quad \phi = \frac{p}{p_b},$$

$$b \quad v^i = \frac{T}{T_b},$$

$$c \quad \eta = \frac{v}{v_b}, \text{ and}$$

$$2.4 \quad \eta = \frac{x}{L}.$$

Since the average temperature within the tube was obtained from the thermal energy remaining in the gas, it is necessary to require that the enthalpy integrated over the volume of the tube equal the thermal energy. Thus,

$$2.5 \quad \Sigma_g = M_T C_v T_{av} = C_v A \int_0^L \frac{T}{V} dx$$

or

$$2.6 \quad T_{av} = \frac{A L}{M_T} \int_0^L \frac{T}{V} d\left(\frac{x}{L}\right).$$

as If we regard  $T(\eta)$ ,  $V(\eta)$ , then 2.6 can be expressed

$$2.7 \quad T_{av} = V_{av} \int_0^1 \frac{T}{V} (\eta) d\eta$$

However, in an ideal gas  $\frac{p}{T} = \frac{RT}{V}$  ;

therefore,

$$2.8a \quad p_{av} = \int_0^1 p(\eta) d\eta, \text{ or}$$

in non-dimensional terms

$$b \quad \phi_{av} = \int_0^1 \phi(\eta) d\eta$$

Sutton (reference book 5, p. 81) has shown that isentropic decay and momentum conservation within the tube demands that

$$2.9 \quad \frac{1}{\phi} = 1 + \gamma M^2, \text{ where } M \text{ is the local mach number.}$$

Also for isentropic expansion:

$$2.10a \quad v^{\frac{2}{\gamma-1}} = \phi^{1/\gamma}$$

$$b \quad v = 1 / \phi^{1/2}$$

$$c \quad a/a_b = v^{1/2} = \phi^{(\gamma-1)/2\gamma}$$

2.11  $M$  can be written as

$$M = \frac{v}{a} = \frac{v}{a_b(a/a_b)} = \frac{v}{a_b \phi^{(\gamma-1)/2\gamma}}$$

As an approximation to equation 1.1, we may state

$$2.12 \quad v = v_0 \eta$$

By further defining

$$2.13 \quad \frac{v_0}{a_b} = \alpha, \text{ 2.11 can be written as}$$

$$2.14 \quad M = \frac{\alpha \eta}{\phi^{(\gamma-1)/2\gamma}}$$

Substitution of the latter expression for  $M$  into 2.9 gives

$$2.15 \quad \eta = \left( \frac{1 - \phi}{\gamma \alpha^2 \phi^{1/\gamma}} \right)^{1/2}$$

This equation expresses  $\phi$  implicitly as a function of  $\eta$ ; and, unfortunately, does not permit a convenient explicit formulation. However, numerical evaluation permits one to establish  $\phi(\eta)$ . Then, numerical evaluation of equation 2.8b determines the relationship  $\phi_{av}(\alpha)$ .

For mass conservation,

$$2.16a \quad M = A \int_0^L \rho \, dx \quad \text{or}$$

$$b \quad 1 = V_{av} \int_0^1 \frac{1}{V(\eta)} \, d\eta.$$

Division of 2.16b by  $V_b$  gives

$$2.17 \quad \frac{1}{K_{av}} = \int_0^1 \frac{d\eta}{K(\eta)}, \quad \text{which with 2.10b give}$$

$$2.18 \quad K_{av} = \left( \int_0^1 \phi^{1/\gamma} d\eta \right)^{-1}.$$

This expression also must be evaluated numerically.

Since the gas behaves nearly ideally,

$$2.19a \quad \frac{pV}{12} = RT \quad \text{and}$$

$$b \quad \frac{p_b V_b}{12} = RT_b.$$

Thus,

$$2.20a \quad \phi K = \gamma \quad \text{and}$$

$$b \quad \phi_{av} K_{av} = \gamma_{av}.$$

If we define a parameter  $\beta$  such that

$$2.21 \quad \beta = \frac{\gamma_o}{\gamma_{av}}, \quad \text{it follows that}$$

$$2.22 \quad \alpha = \beta \gamma_{av}^{1/2}.$$

Having determined  $\phi_{av}$ ,  $\kappa_{av}$ , and  $\gamma_{av}$  as functions of  $\alpha$ , one can with equation 2.22 determine these as functions of  $\beta$ .

An optimum quadratic fit to the numerical values  $\phi_{av}(\beta)$  and  $\kappa_{av}(\beta)$  was performed using a least squares criterion. These quadratics were used in DIPARDIP to calculate  $\phi_{av}$  and  $\kappa_{av}$  to a degree of accuracy warranted by the data.

After projectile ejection, the gas rapidly becomes sonic at the muzzle and equation 2.9 becomes

$$2.23 \quad \phi'_0 = \frac{p_0}{p_b} = \frac{1}{1+\gamma} \quad .$$



## APPENDIX III

### State Variables During the Discharge Period

In appendix III are derived the equations governing the dimensional and non-dimensional state variables as functions of time. The relationship  $n(\xi)$  is also derived for one-dimensional isentropic flow.

For one-dimensional gas discharge from a tube or choked nozzle, the isentropic mass rate of discharge is given by (p. 61, reference book 5).

$$3.1a \quad \dot{M} = \frac{A p_b g \gamma}{a_b} \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} = \frac{C_1^* p_b}{a_b}$$

$$b \quad C_1^* = A g \gamma \left( \frac{2}{\gamma+1} \right)^{\frac{(\gamma+1)}{2(\gamma-1)}}.$$

The average specific volume of the gas within the tube is the total internal volume divided by the mass present within the tube. The mass present at time  $t$  equals the initial total mass minus the mass discharged. Thus,

$$3.2 \quad v_{av} = \frac{V}{M_T - \int_0^t \dot{M} dt}.$$

Also,

$$3.3 \quad v_{av} = \kappa_{av} v_b \text{ and}$$

$$3.4 \quad \frac{v_{b \text{ init}}}{v_b} = \left( \frac{p_b}{p_{b \text{ init}}} \right)^{1/\gamma}.$$

From 3.3 and 3.4 one obtains

$$3.5 \quad v_{av} = \frac{v_{av \text{ init}} \kappa_{av}}{\kappa_{av \text{ init}}} \left( \frac{p_{b \text{ init}}}{p_b} \right)^{1/\gamma}.$$

Elimination of  $v_{av}$  by substitution of the latter expression into 3.2 yields

$$3.6 \quad \frac{V_{av \text{ init}} \kappa_{av \text{ init}} \left( \frac{p_b \text{ init}}{p_b} \right)^{1/\gamma}}{\kappa_{av \text{ init}}} = \frac{\mathcal{V}_T}{M_T - C_1^* \int_0^t p_b / a_b \, dt}.$$

As long as the gas velocity at the muzzle remains sonic,  $\kappa_{av} / \kappa_{av \text{ init}} = 1$ . (Equation 2.23 implies that  $\phi_{av}$  is constant for a choked nozzle.)

Therefore, 3.6 becomes

$$3.7 \quad \left( \frac{p_b \text{ init}}{p_b} \right)^{1/\gamma} = \frac{\mathcal{V}_T / p_b \text{ init} \, V_{av \text{ init}}}{\frac{M_T}{p_b \text{ init}} - C_1^* \int_0^t \frac{p_b}{p_b \text{ init} \, a_b} \, dt}.$$

Let us define

$$3.8 \quad \Phi = \frac{p_b}{p_b \text{ init}}, \text{ so that equation 3.7 may be}$$

written as

$$3.9 \quad \frac{1}{\Phi^{1/\gamma}} = \frac{\mathcal{V}_T / p_b \text{ init} \, V_{av \text{ init}}}{\frac{M_T}{p_b \text{ init}} - C_1^* \int_0^t \frac{\Phi}{a_b} \, dt}.$$

$$\text{But, } \frac{T_b \text{ init}}{T_b} = \left( \frac{p_b \text{ init}}{p_b} \right)^{\frac{\gamma-1}{\gamma}} \text{ or}$$

$$3.10 \quad T_b = T_b \text{ init} \, \Phi^{(\gamma-1)/\gamma}$$

and

$$3.11 \quad a_b = (\gamma g R T_b)^{1/2}; \text{ so that}$$

$$3.12 \quad a_b = a_b \text{ init} \, \Phi^{(\gamma-1)/2\gamma}.$$

Substitution of  $a_b$  in equation 3.12 for that value in 3.9 yields

$$3.13 \quad \Phi^{1/\gamma} = \left[ \frac{M_T}{p_b \text{ init}} - \frac{C_1^*}{a_b \text{ init}} \int_0^t \Phi^{\frac{\gamma+1}{2\gamma}} \, dt \right] \frac{p_b \text{ init} \, V_{av \text{ init}}}{\mathcal{V}_T}.$$

Differentiating both sides of this equation with respect to  $t$  gives

$$3.14 \quad \frac{1}{\gamma} \Phi \frac{1-\gamma}{\gamma} \frac{d\Phi}{dt} = - \frac{C_1^* P_{b \text{ init}} V_{av \text{ init}}}{a_{b \text{ init}} \sqrt{\tau}} \Phi \frac{1+\gamma}{2\gamma} .$$

Letting,

$$3.15 \quad C_2^* = \frac{\gamma C_1^* P_{b \text{ init}} V_{av \text{ init}}}{a_{b \text{ init}} \sqrt{\tau}} ,$$

we have

$$3.16 \quad \Phi^{(1-3\gamma)/2\gamma} d\Phi = -C_2^* dt .$$

Integrating the last expression gives

$$3.17a \quad \frac{2\gamma}{1-\gamma} \Phi^{(1-\gamma)/2\gamma} \Big|_1^{\Phi} = -C_2^* t \quad \text{or}$$

$$b \quad \frac{2\gamma}{\gamma-1} \left( \Phi \frac{1-\gamma}{2\gamma} - 1 \right) = C_2^* t .$$

By use of equations 3.1b, 3.15, and 3.17b, one has

$$3.18 \quad \Phi = \left[ \frac{\gamma(\gamma-1) \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}}{2} \cdot \left( \frac{A g P_{b \text{ init}}}{a_{b \text{ init}} M \tau} \right) t + 1 \right]^{-\frac{2\gamma}{\gamma-1}} .$$

Let us define a dimensionless time  $\tau$  such that

$$3.19a \quad \tau = \alpha_{\tau} t \quad \text{where}$$

$$b \quad \alpha_{\tau} = \frac{A g P_{b \text{ init}}}{a_{b \text{ init}} M \tau} .$$

Finally,

$$3.20 \quad \Phi = \left[ \frac{\gamma(\gamma-1)}{2} \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \gamma+1 \right]^{-\left( \frac{2\gamma}{\gamma-1} \right)}.$$

To compute the momentum rate of discharge from the muzzle, one observes that

$$3.21 \quad \dot{p} = \frac{\dot{M} a'_o}{g}.$$

And from equations 3.1a and 3.21 is derived

$$3.22 \quad \dot{p} = \frac{A \gamma a'_o}{a'_b} \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} p_b.$$

From equations 2.10c and 2.23, one has

$$3.22 \quad \frac{a'_o}{a'_b} = (1+\gamma) \frac{1-\gamma}{2\gamma}.$$

Substitution of the latter expression for  $\frac{a'_o}{a'_b}$  in 3.22 gives

$$3.23 \quad \dot{p} = \frac{\gamma \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}}{(1+\gamma)^{( \gamma-1)/2\gamma}} A p_b.$$

We may also define a dimensionless momentum rate of discharge  $\mu$  as

$$3.24 \quad \mu = \frac{\dot{p}}{A p_{b \text{ init}}}.$$

Then using this and 3.8, we have

$$3.25 \quad \mu = \gamma(1+\gamma)^{-\left( \frac{\gamma-1}{2\gamma} \right)} \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \Phi.$$

It is also desirable to know the total momentum discharged to time  $t$  (assuming that the gas at the muzzle remains sonic). That is

$$3.26 \quad P = \int_0^t \dot{p} dt, \text{ which with 3.24 produce}$$

$$3.27a \quad P = A p_{b \text{ init}} \int_0^t \mu \, dt \quad \text{or}$$

$$b \quad P = \frac{A p_{b \text{ init}}}{\alpha_T} \int_0^T \mu \, dT \quad \text{and}$$

$$c \quad P = \frac{a_{b \text{ init}} M_T}{g} \int_0^T \mu \, dT, \quad \text{from 3.19b.}$$

Defining,

$$3.28 \quad \mu_T = \int_0^T \mu \, dT, \quad \text{we can write 3.27c as}$$

$$3.29 \quad P = \frac{a_{b \text{ init}} M_T}{g} \mu_T.$$

In a similar manner to that in which  $\mu$  was defined, let us define a dimensionless mass rate of discharge  $\gamma$ .

$$3.30a \quad \gamma = \frac{\dot{M} a_{b \text{ init}}}{A g p_{b \text{ init}}}, \quad \text{so that}$$

$$b \quad \dot{M} = \frac{A g p_{b \text{ init}}}{a_{b \text{ init}}} \gamma.$$

From equations 3.1a, 3.8, and 3.30a, one obtains

$$3.31 \quad \gamma = \frac{\Phi \gamma \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma + 1}{2(\gamma - 1)}}}{a_b / a_{b \text{ init}}}.$$

However,

$$3.32 \quad \frac{a_b}{a_{b \text{ init}}} = \left( \frac{p_b}{p_{b \text{ init}}} \right)^{\frac{\gamma - 1}{2\gamma}} = \Phi^{\frac{\gamma - 1}{2\gamma}}$$

Therefore,

$$3.33 \quad \gamma = \gamma \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma + 1}{2(\gamma - 1)}} \Phi^{\frac{\gamma + 1}{2\gamma}}.$$

Let us define the following constants

$$3.34a \quad C_1 = \frac{\gamma(\gamma-1)}{2} \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} = \frac{\gamma-1}{2} C_4 ,$$

$$b \quad C_2 = \frac{2\gamma}{\gamma-1} ,$$

$$c \quad C_3 = \frac{\gamma \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}}{(1+\gamma)} = \frac{C_4}{(\gamma-1)/2\gamma} (1+\gamma) ,$$

$$d \quad C_4 = \gamma \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} , \text{ and}$$

$$e \quad C_5 = \frac{\gamma+1}{\gamma-1} .$$

Then, equation 3.20 becomes

$$3.35 \quad \bar{\Phi} = (C_1 \tau + 1)^{-C_2} .$$

The cumulative breech force to time  $t$ --or breech impulse--is given by

$$3.36 \quad B_\tau = \int_0^t B \, dt , \text{ where}$$

$$3.37a \quad B = A p_b \quad \text{or}$$

$$b \quad B = A p_{b \text{ init}} \bar{\Phi} .$$

Thus,

$$3.38 \quad B_\tau = \frac{A p_{b \text{ init}}}{\alpha_\tau} \int_0^\tau \bar{\Phi} \, d\tau .$$

Defining a dimensionless breech impulse,

$$3.39 \quad \bar{\Phi}_\tau = \int_0^\tau \bar{\Phi} \, d\tau , \text{ we have}$$

$$3.40 \quad B_{\tau} = \frac{A p_b \text{ init}}{\alpha_{\tau}} \Phi_{\tau} .$$

3.39.  $\Phi_{\tau}$  may be found by substitution of  $\Phi$  in 3.35 into One obtains

$$3.41a \quad \Phi_{\tau} = \int_0^{\tau} [C_1 \tau + 1]^{-C_2} d\tau \quad \text{or}$$

$$b \quad \Phi_{\tau} = \frac{1}{C_1(C_2-1)} \left[ 1 - (C_1 \tau + 1)^{-(C_2-1)} \right] .$$

Thus, from 3.25, 3.28, 3.34c, and 3.41b, one can write  $\mu_{\tau}$  as

$$3.42 \quad \mu_{\tau} = \frac{C_3}{C_1(C_2-1)} \left[ 1 - (C_1 \tau + 1)^{-(C_2-1)} \right] .$$

Further, it is desired to have the cumulative mass discharged to time  $t$ . This is given by

$$3.43 \quad M = \int_0^t \dot{M} dt .$$

Substitution of  $\dot{M}$  in equation 3.30b into 3.43 gives

$$3.44 \quad M = M_{\tau} \int_0^{\tau} \nu d\tau .$$

The latter may be expressed as

$$3.45 \quad M = M_{\tau} \nu_{\tau} \quad \text{where}$$

$$3.46 \quad \nu_{\tau} = \int_0^{\tau} \nu d\tau , \quad \text{a dimensionless cumulative mass discharged.}$$

$\nu_{\tau}$  can be found by substitution of  $\nu$  in equation 3.33 into 3.46 . Using the constants defined in 3.34,  $\nu_{\tau}$  may be expressed as

$$3.47 \quad \nu_{\tau} = \frac{C_4}{C_1(C_5-1)} \left[ 1 - (C_1 \tau + 1)^{-(C_5-1)} \right] .$$

The total energy rate of discharge or stagnation enthalpy rate of discharge is given by

$$3.48 \quad \dot{H} = C_p T_{av} \dot{M} .$$

However,

$$3.49a \quad C_p = \frac{\gamma R}{(\gamma - 1)J} \quad \text{and}$$

$$b \quad T_{av} = T_{av \text{ init}} \Phi^{\frac{\gamma-1}{\gamma}} .$$

From equations 3.30b, 3.48, and 3.49,

$$3.50 \quad \dot{H} = \frac{\gamma R}{(\gamma - 1)J} \frac{T_{av \text{ init}} A g p_b \text{ init}}{a_b \text{ init}} \gamma \Phi^{\frac{\gamma-1}{\gamma}}$$

that is, with 3.33 and 3.35

$$3.51 \quad \dot{H} = \frac{\gamma R}{(\gamma - 1)J} \frac{T_{av \text{ init}} A g p_b \text{ init}}{a_b \text{ init}} .$$

$$. \quad C_4 \left[ C_1 \tau + 1 \right]^{-(C_5+2)} .$$

or, from 1.15, 3.19b, and 3.51, we have

$$3.52 \quad \dot{H} = E_g \alpha_T \gamma C_4 \left[ C_1 \tau + 1 \right]^{-(C_5+2)} .$$

Defining a dimensionless stagnation enthalpy rate of discharge  $\eta$  as

$$3.53 \quad \eta = \gamma C_4 \left[ C_1 \tau + 1 \right]^{-(C_5+2)} , \quad \text{one obtains for } \dot{H}$$

$$3.54 \quad \dot{H} = E_g \alpha_T \eta .$$

The cumulative stagnation enthalpy discharged is, then,

$$3.55 \quad H = \int_0^t \dot{H} dt \quad \text{or from the preceding two relations}$$

$$3.56 \quad H = E_g \int_0^\tau \eta d\tau .$$



With the definition

$$3.57 \quad \eta_{\tau} = \int_0^{\tau} \eta \, d\tau \quad , \text{ equation 3.56 becomes}$$

$$3.58 \quad H = E_g \eta_{\tau} \quad .$$

One can obtain a computational expression for  $\eta_{\tau}$  from 3.53 and 3.57 as follows

$$3.59 \quad \eta_{\tau} = \frac{\gamma C_4}{C_1(C_5+1)} \left[ 1 - (C_1\tau+1)^{-(C_5+1)} \right] \quad .$$

All of the non-dimensional parameters were evaluated as functions of  $\tau$  for  $\gamma = 1.26$  in the equations:

3.20 or 3.35 for  $\bar{\Phi}$

3.25 for  $\mu$

3.33 for  $\nu$

3.53 for  $\eta$

3.41b for  $\bar{\Phi}_{\tau}$

3.42 for  $\mu_{\tau}$

3.47 for  $\nu_{\tau}$

3.59 for  $\eta_{\tau}$

Auxiliary constants are defined in 3.34a thru e.

### Derivation of the Relationship: $n(\epsilon)$

In appendices IV and V a relationship is required which exists between the velocity to throat velocity ratio and the area to throat area ratio in one-dimensional, isentropic flows. The following is a derivation of this relationship.

In any of the books listed in the BIBLIOGRAPHY, are found one-dimensional, isentropic flow formulas involving the variables:  $M$ , mach number;

$\epsilon$ , expansion ratio;

$\frac{T}{T_b}$ , temperature ratio; and

$\frac{a}{a_b}$  ratio of speed of sound to stagnation speed of sound.

The subscript "b" is used here to denote a stagnation value or the value of the variable at the breech of a tube. The subscript "o" denotes the value of the variable at the muzzle or throat. Variables without subscripts are evaluated at a station downstream of the throat.

The formulas used in the derivation are:

$$3.60 \quad \epsilon = \frac{S}{A_o}, \text{ by definition.}$$

$$3.61 \quad n = \frac{v}{a_o}, \text{ by definition.}$$

$$3.62 \quad \frac{1}{\epsilon^2} = M^2 \left[ \frac{1 + \frac{\gamma - 1}{2}}{1 + \frac{(\gamma - 1)}{2} M^2} \right]^{\frac{\gamma + 1}{\gamma - 1}},$$

from isentropic flow theory.

$$3.63 \quad M^2 = \frac{v^2}{\gamma g R T}, \text{ by definition.}$$

$$3.64 \quad \frac{T_b}{T} = 1 + \frac{\gamma - 1}{2} M^2, \text{ from isentropic flow theory.}$$

$$3.65 \quad \frac{a_o}{a_b} = (1 + \gamma) \frac{1 - \gamma}{2\gamma}, \text{ from isentropic flow theory.}$$

3.66  $a_b = (\gamma g R T_b)^{1/2}$ , by regarding sound propagation as a strictly adiabatic process. Substitution of T from 3.63 into 3.64 gives

3.67  $T_b(M^2 \gamma g R) = v^2(1 + \frac{\gamma - 1}{2} M^2)$ , which by 3.66 becomes

$$3.68 \quad M^2 a_b^2 = v^2(1 + \frac{\gamma - 1}{2} M^2)$$

Elimination of  $a_b$  between 3.65 and 3.68 yields

$$3.69 \quad n^2 = \left(\frac{v}{a_0}\right)^2 = \frac{M^2 (1 + \gamma) \frac{\gamma - 1}{2}}{1 + \frac{\gamma - 1}{2} M^2}.$$

By solving this expression for  $M^2$ , we get

$$3.70 \quad M^2 = \frac{n^2}{(1 + \gamma) \frac{\gamma - 1}{2} - \left(\frac{\gamma - 1}{2\gamma}\right) n^2}.$$

Substitution of this value of  $M^2$  into 3.62 produces

$$3.71 \quad \frac{1}{\epsilon^2} = \frac{n^2}{a - bn^2} \left[ \frac{\gamma + 1}{2 + \frac{(\gamma - 1)n^2}{a - bn^2}} \right]^c, \quad \text{where}$$

$$a = (1 + \gamma) \frac{\gamma - 1}{2}$$

$$b = \frac{\gamma - 1}{2}$$

$$c = \frac{\gamma + 1}{\gamma - 1}$$

This formula defines  $n$  implicitly as a function of  $\epsilon$  and has been evaluated numerically for  $\gamma = 1.26$  to obtain the tabular relationship used in DIPARDIP.

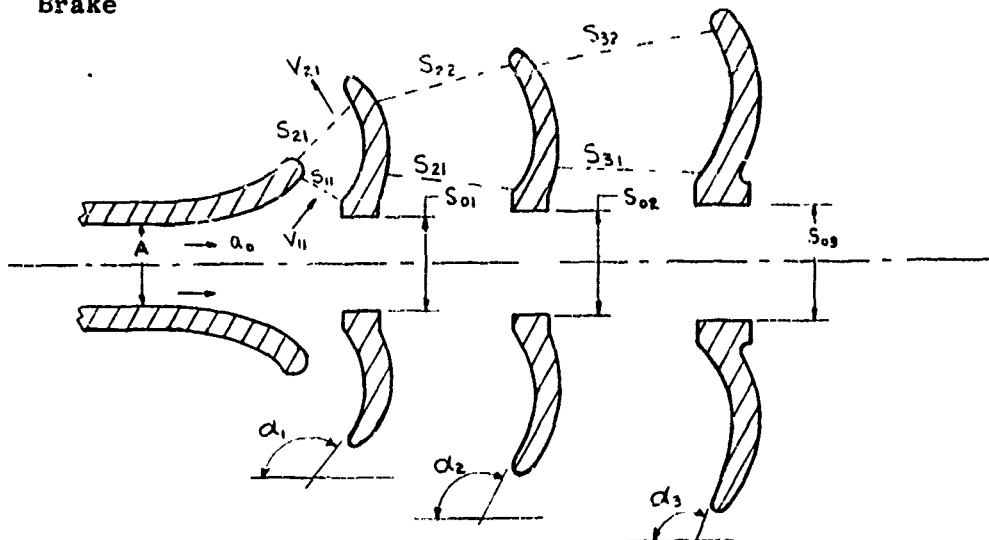
## APPENDIX IV

### Formulas for Closed Brakes

As was shown in the report "Muzzle Brakes" by Hammer (Document No. 7 in the BIBLIOGRAPHY), the derivation of the equations for closed brake designs is based upon finding the change in the momentum flux thru a control volume enclosing the brake.

Regard figure 4.1 .

Figure 4.1 . Schematic Plan View of Triple-Baffle, Closed Brake



Regarding the passage of gas toward the first baffle, it can be seen that, with the brake flowing full (i.e., with no separation), the gas captured by the baffle will have experienced an approximate area expansion of

$$4.1 \quad \epsilon_{11} = \frac{S_{01} + S_{11}}{A}$$

when it starts to be deflected by the first baffle. This gas will have a speed

$$4.2 \quad |v_{11}| = a_0 \cdot n(\epsilon_{11}) = a_0 \cdot n_{11} .$$

$n$  is the speed up factor developed in appendix III.

It is also apparent that this gas experiences further expansion by a factor  $\frac{S_{21}}{S_{11}}$ . Thus, the resultant total

expansion of the gas caught and turned by the first baffle is

$$4.3 \quad \epsilon_{21} = \epsilon_{11} \frac{S_{21}}{S_{11}}$$

The speed of the gas as it leaves the first baffle is

$$4.4a \quad |v_{21}| = a_0 n_{21}, \quad \text{where}$$

$$b \quad n_{21} = n(\epsilon_{21}).$$

If the mass flux thru  $S_{01}$  is the same as that thru  $S_{11}$ , a fraction of the mass flow  $\dot{M}_0$  equal to

$$4.5 \quad r_1 = \frac{S_{11}}{S_{01} + S_{11}} \quad \text{will be caught by the first}$$

baffle. For mass conservation, a fraction

$$4.6 \quad K_1 = \frac{S_{01}}{S_{01} + S_{11}} \quad \text{will be passed without deflection by this baffle.}$$

We assume that  $v_{11}$  is nearly paraxial and that  $v_{21}$  makes an angle of  $\alpha_1$  with respect to the axis.

For momentum conservation, the force felt by the first baffle equals the difference in the momentum fluxes entering and leaving it in the axial direction. Thus,

$$4.7a \quad F_{z1} = \dot{M}_0 r_1 |\vec{v}_{11}| - \dot{M}_0 r_1 |\vec{v}_{21}| \cos \alpha_1$$

$$b \quad F_{z1} = \dot{M}_0 r_1 a_0 n_{11} - \dot{M}_0 r_1 a_0 n_{21} \cos \alpha_1$$

or

$$c \quad F_{z1} = \dot{M}_0 a_0 r_1 (n_{11} - n_{21} \cos \alpha_1).$$

The gas which passes the first baffle undeflected has expanded in cross-sectional area by a factor  $\epsilon_{11}$ . For full flow into the second baffle, the total area expansion from the muzzle is, therefore,

$$4.8 \quad \epsilon_{12} = \epsilon_{11} \left( \frac{S_{02} + S_{12}}{S_{01}} \right).$$

Further expansion of the deflected gas results in an expansion ratio of

$$4.9 \quad \epsilon_{22} = \frac{S_{22}}{S_{12}} \epsilon_{12} \quad \text{as the gas leaves the baffle.}$$

The velocities of entrance to and exit from the second baffle corresponding to these expansion ratios are, respectively,

$$4.10a \quad v_{12} = a_c n(\epsilon_{12}) = a_o n_{12}$$

and

$$b \quad v_{22} = a_o n(\epsilon_{22}) = a_o n_{22} .$$

Since only a fraction  $K_1$  of the total mass flux enters the second baffle, the fraction turned by this baffle is

$$4.11 \quad r_2 = \frac{S_{12}}{S_{02} + S_{12}} K_1 \quad \text{and}$$

the fraction of the total passing undeflected is

$$4.12 \quad K_2 = \frac{S_{02}}{S_{02} + S_{12}} K_1 .$$

Again, using the momentum rate of change principle, we find that the force on the second baffle in the axial direction is

$$4.13 \quad F_{z2} = \dot{M}_o a_o r_2 (n_{12} - n_{22} \cos \alpha_2) .$$

By the same reasoning, the force on the third baffle is

$$4.14 \quad F_{z3} = \dot{M}_o a_o r_3 (n_{13} - n_{23} \cos \alpha_3) .$$

The total brake force in the axial direction is simply the sum of the forces on each baffle, i.e.,

$$4.15 \quad F_z = F_{z1} + F_{z2} + F_{z3} \quad \text{or}$$

$$4.16 \quad F_z = \dot{M}_o a_o \sum_j r_j (n_{1j} - n_{2j} \cos \alpha_j) , \quad \text{where}$$

$$4.17a \quad n_{1j} = n(\epsilon_{1j})$$

$$b \quad n_{2j} = n(\epsilon_{2j}) \quad \text{and}$$

$$4.18a \quad \epsilon_{1j} = \left( \frac{S_{0j} + S_{1j}}{S_{0j-1}} \right) \epsilon_{1j-1}$$

$$b \quad \epsilon_{10} = 1$$

$$c \quad S_{00} = A$$

$$4.19 \quad \epsilon_{2j} = \frac{S_{2j}}{S_{1j}} \epsilon_{1j}$$

$$4.20a \quad r_j = \left( \frac{S_{1j}}{S_{0j} + S_{1j}} \right)^{K_j - 1}$$

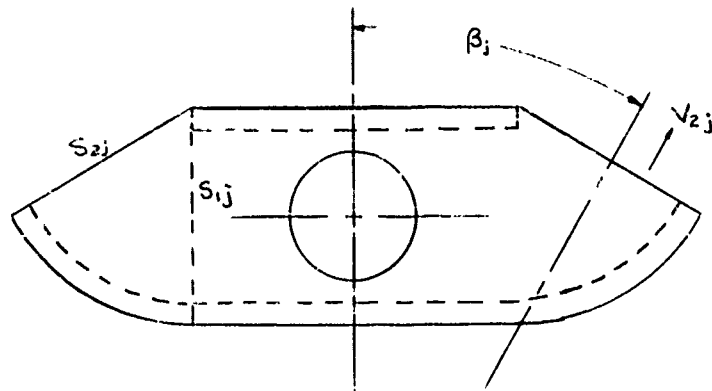
$$b \quad K_0 = 1$$

$$4.21 \quad K_j = \left( \frac{S_{0j}}{S_{0j} + S_{1j}} \right)^{K_j - 1} .$$

For brakes which exhaust gas asymmetrically with respect to the vertical, at zero quadrant elevation, there is an additional vertical force on the brake.

Regard figure 4.2 .

Figure 4.2 . Schematic Front View of Asymmetric, Closed Brake



For the  $j^{\text{th}}$  baffle, the gas which escapes thru the area  $S_{2j}$  is moving with speed  $|v_{2j}|$  at an angle  $\beta_j$  with respect to the vertical. Since this is a closed brake, the previous analysis which produced formulas 4.16 thru 4.21 is valid here.

The downward vertical force on the brake is simply equal to the vertical component of the rate of change of

momentum. Since gas impinges upon each baffle without having a vertical velocity component, the vertical force equals the vertical momentum flux. That is,

$$4.22a \quad F_y = \sum_j r_j \dot{M}_0 |v_{2j}| \cos \beta_j \quad \text{or}$$

$$b \quad F_y = \dot{M}_0 a_0 \sum_j r_j n_{2j} \cos \beta_j .$$

It is convenient to define several non-dimensional parameters which are useful in computing forces on closed muzzle brakes. These are:

$$4.23a \quad \lambda = \frac{F_z}{\dot{p}} ,$$

$$b \quad b = \frac{F_z}{B} , \text{ the momentum index}$$

$$c \quad \lambda_r = \frac{\text{total momentum flux in axial direction thru a control surface completely enclosing the brake}}{\dot{p}}$$

$\lambda$  and  $b$  are alternative ways of defining a non-dimensional axial brake force.  $\lambda_r$  is a non-dimensional parameter of interest in evaluating the strength of the induced atmospheric shock.

For closed brakes,  $\frac{F_z}{B}$  is taken to be a constant throughout the discharge period; hence

$$4.24a \quad b = \frac{\int_0^\infty F_z dt}{B_\tau} \quad \text{or}$$

$$b \quad b B_\tau = \int_0^\infty F_z dt .$$

The resultant axial impulse felt by the weapon is

$$4.25 \quad I_z = B_\tau - \int_0^\infty F_z dt .$$



By 4.24b, the last expression may be written as

$$4.26 \quad I_z = B_T (1 - b).$$

One also can define a non-dimensional vertical brake force  $\omega$ .

$$4.27 \quad \omega = \frac{F_y}{\dot{P}}$$

By integration of this expression, one obtains the resultant vertical impulse  $I_y$ .

$$4.28 \quad I_y = \omega P.$$

To find computational expressions for  $\lambda$ ,  $b$ ,  $\lambda_r$ , and  $\omega$ , one need merely make appropriate substitutions in 4.23 and 4.27 for the dimensional parameters involved. For example, from 3.21, 4.16, and 4.23a, one finds

$$4.29 \quad \lambda = \sum_j^N r_j (n_{1j} - n_{2j} \cos \alpha_j).$$

Due to the simplifying assumptions made in the derivation of 4.29, this expression is adjusted to agree with experiments performed on closed baffles, by means of a correction factor  $\frac{1}{F_0}$ .

Thus

$$4.30 \quad \lambda = \frac{1}{F_0} \sum_j^N r_j (n_{1j} - n_{2j} \cos \alpha_j).$$

From 4.23b and the last expression, the momentum index can be written as

$$4.31 \quad b = \frac{\dot{P}}{B} \frac{1}{F_0} \sum_j^N r_j (n_{1j} - n_{2j} \cos \alpha_j).$$

The axial component of the corrected momentum transport thru a control surface enclosing the brake can be written as

$$\frac{\dot{M} a_z}{F_1} \left[ \sum_j^N r_j n_{2j} \cos \alpha_j - n_{2N} \left( 1 - \sum_j^N r_j \right) \right].$$

With 3.21 and 4.23c this expression produces

$$4.32 \quad \lambda_r = \frac{1}{F_1} \left[ \sum_j^N r_j n_{2j} \cos \alpha_j - n_{2N} \left( 1 - \frac{N}{2} r_j \right) \right] .$$

Finally, using an empirical correction factor  $\frac{1}{F_2}$ ,  
equations 3.21, 4.22b, and 4.27 yield

$$4.33 \quad \omega = \frac{1}{F_2} \sum_j^N r_j n_{2j} \cos \beta_j .$$

## APPENDIX V

### Formulas for Open Brakes

For single-baffle, symmetric, open brakes, the region between the muzzle and the baffle remains relatively open for free expansion of the gas prior to deflection. The baffle is mechanically connected to a tube attached to the muzzle by supports which partially confine the flow. However, even without ducting of the flow, confinement is achieved by the shock envelope which develops in flow from sonic and supersonic nozzles.

Regard figure 5.1 .

Figure 5.1a Schematic Plan View of a Single-Baffle, Open Brake

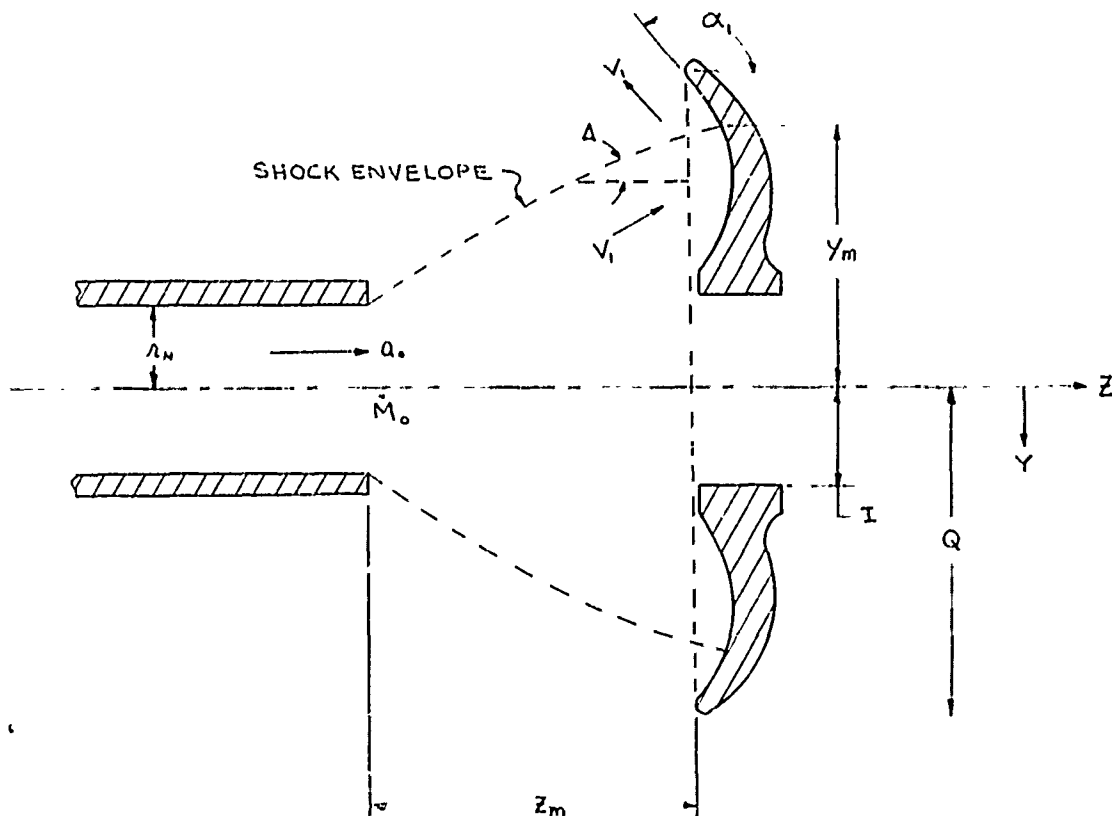
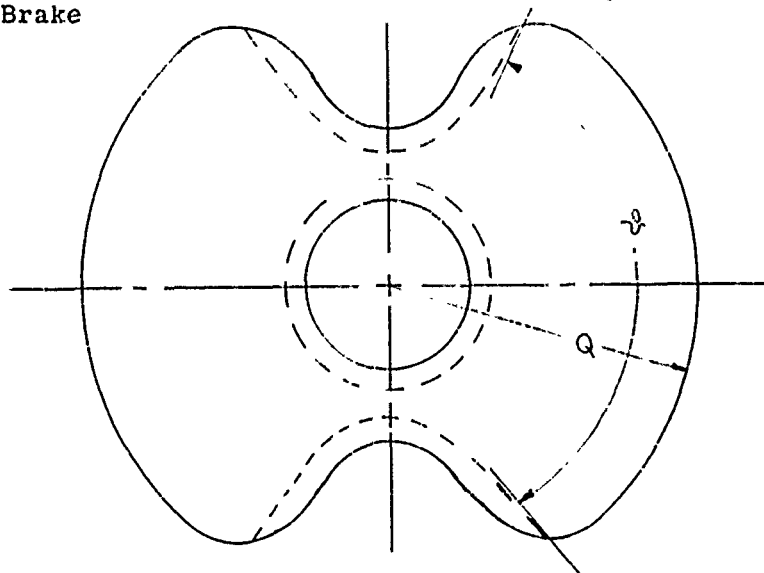


Figure 5.1b Schematic Front View of a Single-Baffle, Open Brake



In the absence of a muzzle brake, the free discharge from the tube would cause a shock envelope to develop in the flow. This has been sketched in in figure 5.1a . The presence of the brake would alter the flow pattern considerably and consequently alter any shock structure within the flow. However, it is not unreasonable to expect that the fraction of the total mass flux captured and turned by the baffle could be computed by assuming that that portion is captured which would be masked by a virtual baffle in a corresponding position of the free stream. With this as a working hypothesis, it is necessary to be able to predict the free stream shock envelope. A method for doing this is described in document number 1 of the BIBLIOGRAPHY. This method was used for a sonic nozzle with  $\gamma = 1.26$  for several values of  $p_0$  , and the resulting envelopes  $\lambda(\sigma)$  were

optimally fit with quadratic and cubic equations in  $\sigma$  .

For the case pictured in figure 5.1a, that is, when  $y_m \leq Q$ , the mass fraction captured and deflected by the baffle is given by

$$5.1a \quad r_1 = \frac{\dot{M}_1}{\dot{M}_0} = \frac{\pi y_m^2 - \pi I^2}{\pi y_m^2} \quad \text{or}$$

$$b \quad r_1 = 1 - \frac{I^2}{y_m^2}, \quad (y_m \leq Q).$$

However, for  $y_m > Q$ , the gas deflected by the baffle equals the total amount minus that lost thru the center and that which would be lost by spilling over the outer edge. This mass is

$$5.2 \quad \dot{M}_1 = \frac{\dot{M}_0}{\pi y_m^2} \left[ \pi y_m^2 - \pi I^2 - \pi \frac{\gamma \ell}{\pi} (y_m^2 - Q^2) \right].$$

The fraction captured is

$$5.3 \quad r_1 = 1 - \frac{\gamma \ell}{\pi} \div \left( \frac{\gamma \ell}{\pi} Q^2 - I^2 \right) / y_m^2, \quad (y_m > Q).$$

The momentum flux in the z- direction into a control surface surrounding the baffle is

$$5.4 \quad \dot{P}_1 = v_1 \dot{M}_1 \cos \Delta = v_1 \dot{M}_0 r_1 \cos \Delta$$

and the momentum flux in the z- direction out of the control surface is

$$5.5 \quad \dot{P}_2 = v_1 \dot{M}_1 \cos \alpha_1 = v_1 \dot{M}_0 r_1 \cos \alpha_1.$$

For momentum conservation,

$$5.6 \quad \dot{P}_1 - \dot{P}_2 = F_z, \text{ which from equations 5.4 and 5.5} \\ \text{may be written as}$$

$$5.7 \quad F_z = \dot{M}_0 r_1 v_1 (\cos \Delta - \cos \alpha_1).$$

Using the speed-up factor,  $n$ , developed in appendix III, we can write

$$5.8a \quad v_1 = n_{21} a_0, \quad \text{where}$$

$$b \quad n_{21} = n(\epsilon_{21})$$

$$c \quad \epsilon_{21} \approx 1 + \frac{\gamma \ell}{\pi} \left( \frac{y_m}{r_N} \right)^2 \quad \text{and}$$

d  $\Delta \approx 0$ , for the weapons under consideration. Equations 5.7 and 5.8a and d give

$$5.9 \quad F_z = \dot{M}_0 a_0 n_{21} r_1 (1 - \cos \alpha_1).$$

It is recognized that non-uniformity in the density distribution and non-paraxial flow into the baffle will give rise to a value of  $F_z$  slightly different from that predicted by equation 5.9 . Therefore,  $F_z$  has been corrected with an empirical correction factor  $1/f_3$  .  $f_3$  has been found to be approximately 1.33 . Thus,

$$5.10 \quad F_z = \dot{M}_0 a_0 \frac{n_{21} r_1 (1 - \cos \alpha_1)}{f_3} \quad \text{or}$$

$$5.11 \quad \lambda = \frac{F_z}{\dot{p}} = \frac{n_{21} r_1 (1 - \cos \alpha_1)}{f_3} .$$

By 4.23b and 5.11 ,

$$5.12 \quad b = \frac{\dot{p}}{B} \frac{n_{21} r_1 (1 - \cos \alpha_1)}{f_3} .$$

Since the open brake was assumed to be symmetric with respect to a horizontal axis,  $\omega = 0$  .

It should be noted that in the expression for  $b$  ,  $n_{21}$  and  $r_1$  both depend upon the dimensions of the shock envelope. Since the latter changes markedly throughout the discharge period, one should expect to find some change in  $b$  as a function of time (See graph 5.1.) .

Artillery designers are fundamentally concerned with an effective momentum index in order to compute the total impulse which must be taken up by the recoil mechanism. The engineer, therefore, is not primarily concerned with the instantaneous value of  $b$  . To find the effective value of  $b$  which the engineer uses, we note that the resultant axial impulse is given by

$$5.13 \quad I_z = B_T - \int_0^{\infty} F_z dt .$$

However, from 4.23b, the definition of  $b$  ,

$$5.14 \quad F_z = b B; \text{ hence}$$

$$5.15a \quad I_z = B_T - \int_0^{\infty} b B dt \quad \text{or}$$

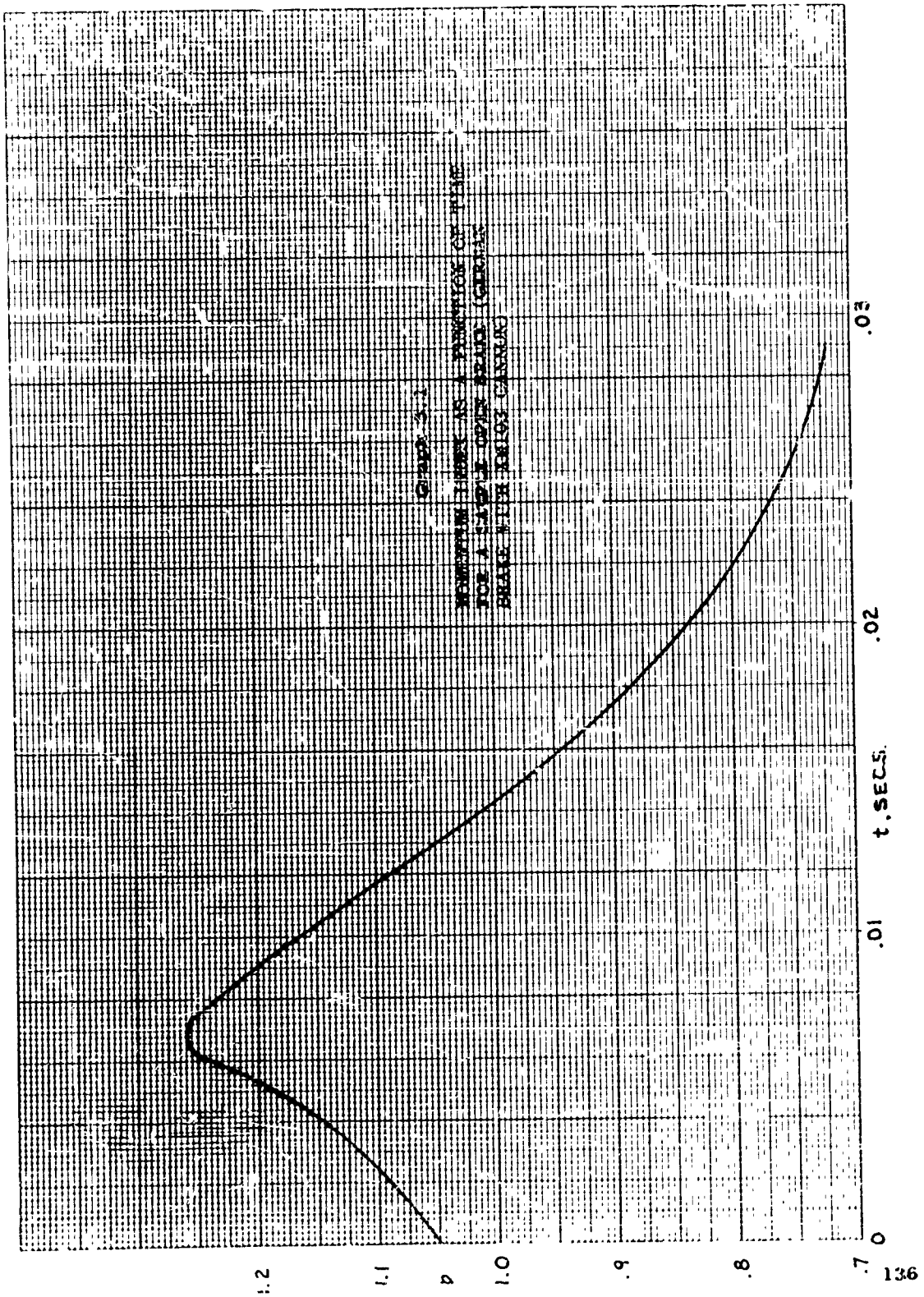
$$b \quad I_z = B_T - \int_0^{B_T} b dB_T .$$

The effective value of  $b$ ,  $b_{\text{eff}}$ , which the engineer uses is obtained from

$$5.16 \quad I_z = B_T (1 - b_{\text{eff}}) .$$

Comparing equations 5.15b and 5.16, it is apparent that  $b_{\text{eff}}$  should be

$$5.17 \quad b_{\text{eff}} = \frac{\int_0^{B_T} b \, dB_T}{B_T} .$$





Therefore, the downward force due to efflux thru this portion of the periphery and its mirror image with respect to the vertical can be written as

$$6.3a \quad F_{y1} = 2v_{21} K \int_{-\vartheta_1}^{\vartheta_2} \sin \vartheta d\vartheta \quad \text{or}$$

$$b \quad F_{y1} = 2v_{21} K (\cos \vartheta_1 - \cos \vartheta_2), \quad \text{where}$$

$$c \quad K = \frac{\dot{M}_0 r_1}{2\pi}$$

For peripheral discharge thru  $-\frac{\pi}{2} \leq \vartheta < -\vartheta_1$  and

its mirror image, all of the mass is assumed to be deflected thru  $\vartheta_3$ . Thus, the contribution to the downward force from this momentum discharge is

$$6.4 \quad F_{y2} = 2Kv_{21} (\sin \vartheta_3) (\pi/2 - \vartheta_1)$$

No flux passes thru the periphery  $\vartheta_2 < \vartheta \leq \frac{\pi}{2}$

and its mirror image and, hence, there is no vertical force component for this portion of the periphery. The total downward force is, therefore,

$$6.5a \quad F_y = 2v_{21} K \left[ (\cos \vartheta_1 - \cos \vartheta_2) + \left(\frac{\pi}{2} - \vartheta_1\right) \sin \vartheta_3 \right] \quad \text{or}$$

$$b \quad F_y = \frac{\dot{M}_0 r_1 v_{21}}{\pi} \left[ (\cos \vartheta_1 - \cos \vartheta_2) + \left(\frac{\pi}{2} - \vartheta_1\right) \sin \vartheta_3 \right].$$

From equations 4.4 and 4.27, and 6.5b,  $\omega$  can be written as

$$6.6 \quad \omega = \frac{r_1 n_{21}}{\pi} \left[ (\cos \vartheta_1 - \cos \vartheta_2) + \left(\frac{\pi}{2} - \vartheta_1\right) \sin \vartheta_3 \right].$$

For a multiple baffle brake, this expression becomes

$$6.7 \quad \omega = \frac{1}{\pi} \sum_j^N n_{2j} r_j \left[ (\cos \vartheta_{1j} - \cos \vartheta_{2j}) + \left(\frac{\pi}{2} - \vartheta_{1j}\right) \sin \vartheta_{3j} \right].$$

As indicated in appendix IV,

$$6.8a \quad F_y = \omega \dot{P} \quad \text{and}$$

$$b \quad I_y = \omega P.$$

## BIBLIOGRAPHY

### BOOKS

1. Courant, R. and Friedrichs, K. O. Supersonic Flow and Shock Waves, New York: Interscience Publishers, Inc., 1956.
2. Keenan, J. H. and Kaye, J. Gas Tables, New York: John Wiley and Sons, Inc., 1944.
3. Pai, Shih-I. Fluid Dynamics of Jets, New York: D. Van Nostrand, Inc., 1945.
4. Shapiro, A. H. The Dynamics and Thermodynamics of Compressible Fluid Flow, Vols. I and II, New York: The Ronald Press Co., 1953.
5. Sutton, G. P. Rocket Propulsion Elements, New York: John Wiley and Sons, Inc., 1956.

### DOCUMENTS

1. Adamson, T. C., Jr. and Nicholls, J. A. "On the Structure of Jets from Highly Underexpanded Nozzles into Still Air," Rpt. No. 2397-5-F, University of Michigan Research Institute, Ann Arbor, Michigan, 1958.
2. Berning, W. W. "Investigation of the Propagation of Blast Waves Over Relatively Large Distances and the Damaging Possibilities of Such Propagation," BRL Rpt. No. 675, Aberdeen Proving Ground, Maryland, November 1958.
3. Brode, H. L. "Space Plots of Pressure, Density, and Particle Velocity for the Blast Wave from a Point Source in Air," RM-1913-AEC, ASTIA Document Number AD133043, Rand Corp., Santa Monica, California, June 1957.
4. Cleaver, J. W. "The Two-Dimensional Flow of an Ideal Dissociating Gas," Rpt. No. 123, College of Aeronautics, Cranfield, December 1959.
5. Cole, J. D. "Note on the Directional Effects of Pressure Field of Moving Blast," RM-848, The Rand Corporation, Santa Monica, California, June 1952.

6. Groak, G. S., Jr. "An Evaluation of the Performance of Three Types of Muzzle Brakes for the 155mm Howitzer, T258," Report No. DPS/TW-103/4, Development and Proof Services, Aberdeen Proving Ground, Maryland, May 1960.
7. Hammer, E. W., Jr. "Muzzle Brakes, Vols. I and II," Franklin Institute Laboratories, Ordnance Department, U. S. Army, June 1949.
8. Ho, D. V. "Notes on Shock Propagation in a Non-Uniform Duct," Tech. Rpt. No. 4, OOR #2311:4, Division of Applied Mathematics, Brown University, Providence, R. I., November 1960.
9. Holland, Howard, Jr. "Muzzle Blast Measurements on Howitzer 105mm, M2A2E2 with Muzzle Brake No. 8," TM 12-60, U.S.A. Ordnance Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, August 1960.
10. Love, E. S., Grigsby, C. E., et al. "Experimental and Theoretical Studies of Axisymmetric Free Jets," NASA TR R-6, National Aeronautics and Space Administration, Langley Research Center, Langley Field, Virginia, 1959.
11. Munch, N. E., MacKay, M. W., and Greengrove, R. T. "90 MM Gun Blast Deflector Development, Vol. I, Summary Report," (CONFIDENTIAL), Watervliet Arsenal, Watervliet, New York, September 1955.
12. Munch, N. E., MacKay, M. W., and Greengrove, R. T. "90 MM Gun Blast Deflector Development, Vol. II, Reference Information," Watervliet Arsenal, Watervliet, New York, September 1955.
13. Neice, Stanford E. "A Method for Stabilizing Shock Waves in Channel Flow by Means of a Surge Chamber," N.A.C.A. Tech. Note 2694, National Advisory Committee for Aeronautics, Washington, D. C., June 1953.
14. Romba, J. J. and Martin, P. "The Propagation of Air Shock Waves on a Biophysical Model," U. S. Army Ordnance Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, September 1961.
15. Thornhill, C. K. "Explosions in Air," (CONFIDENTIAL) A.R.D.E. Memorandum B57/60, Armament Research and Development Establishment, Secretary of the War Office, Whitehall, London, England, September 1960.

16. "Investigation of Muzzle Blast of Howitzer, 155-MM M1A2E3," Report No. DPS-169, Development and Proof Services, Aberdeen Proving Ground, Maryland, March 1961.
17. "Report on Development Test of Muzzle Brakes (Single Baffle) for 76MM Gun, T124E2," Eleventh Report on Ordnance Project No. TR1-1037, Development and Proof Services, Aberdeen Proving Ground, Maryland, December 1956.
18. "First Report on Effect of Blast from Muzzle Brake M2, Mounted on 75MM Antiaircraft Gun, T6, on the Performance of the Gun Crew," Aberdeen Proving Ground, Maryland, August 1949.
19. "First Report on Test of the Effectiveness of the 4-G Type Muzzle Brake and the British Standard Single-Baffle Muzzle Brake, FL-5800, Toward Improvement of the Stability of the 57MM Gun Carriage, M1A2," Aberdeen Proving Ground, Maryland, June 1945.
20. "The Distribution of Blast Pressure Near the Muzzle of a 6 PR. Anti-Tank Gun With and Without a Muzzle Brake," (SECRET). Note No. MOS/405/VJJ, Department of Scientific and Industrial Research, Road Research Laboratory, Report to the British Ministry of Supply, October 1944.

### ACKNOWLEDGEMENT

The author would like to acknowledge the assistance of Mr. Stuart Olson in the preparation of charts and graphs and in the proof reading of this report.

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